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The efficiency of Portuguese Technology Transfer Offices and the importance of universities' characteristics

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Short Bio

André Monteiro was born in Porto, Portugal, on January 19, 1989. He finished his high school education in 2007 and started undergraduate studies in *Faculdade de Economia e Gestão da Universidade de Católica Portuguesa* in 2008. In 2011 he received the *Licenciatura em Gestão* degree. He initiated post graduate formation in 2011 and is presently enrolled in the *Mestrado em Economia e Gestão da Inovação* at *Faculdade de Economia da Universidade do Porto* with the dissertation entitled "The efficiency of Portuguese Technology Transfer Offices and the importance of universities' characteristics".

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Abstract

University Technology Transfer Offices (TTOs) have proliferated in the last few decades based on the reasoning that they play a significant role in the diffusion of innovation, and are important catalysts to regional development. Studies on the efficiency of TTOs have mainly focused on well-developed countries (US and UK), whereas intermediate technology countries have been rather neglected. This study intends to complement existing empirical work on this matter by providing evidence on Portugal, an intermediate technology country which has invested quite heavily in technological support infrastructures (including TTOs) in the last decade. Using the Data Envelopment Analysis (DEA) approach to 18 Portuguese Technology Transfer Offices (TTOs) associated to the UTEN network over the period 2007-2011, we found that TTOs had improved their efficiency especially in the more upstream stages of the technology transfer process (invention disclosures and priority filings) but saw their efficiency drop drastically in the more downstream stages (research agreements and spin-off/start-up companies established). Additionally, based on econometric models, we found that universities with a large number of accumulated patents and publications are associated to more efficient TTOs in terms of invention disclosures and priority filings. Moreover, the regional industrial basis, most notably the weight of the manufacturing industry and new high- and medium-tech firms in regions where the university is located, contributes significantly to the efficiency of TTOs, in both the more upstream (invention disclosure and priority filings) and downstream (start-ups) phases, reflecting the importance of strong business regional spillovers on their efficiency.

Keywords: Technology Transfer Offices; Efficiency; Data Envelopment Analysis; Universities; Portugal

JEL-Codes: O34; O39; C14

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1. Introduction

University-Industry (U-I) relationships have been the focus of a growing number of studies, particularly since the 1990s (Teixeira and Mota, 2012). The relevance of cooperation between University and Industry has been highlighted by several authors (e.g., Agrawal, 2001; Bekkers and Freitas, 2008) who stress, for instance, that universities can contribute to regional development through the production and transfer of knowledge (Colombo *et al*., 2009; Bergman, 2010).

In this field, one of the first active, economically driven innovation policies adopted and adapted globally by countries worldwide was the Bayh-Dole Act (BDA), implemented in 1980 in the United States of America. As a result of this law, US universities, small businesses and non-profits began to take control of the intellectual property of their inventions (Aldridge and Audretsch, 2011). The BDA is considered an example for commercially-focused innovation (Gibson and Naquin, 2011) and therefore, several European countries, such as France, the UK, Sweden and Italy, have followed the lines of this policy. Likewise, at the European Union level, incentive policies for the management of Intellectual Property (IP) were implemented (Gibson and Naquin, 2011).

In the specific case of Portugal, a network of Industrial Property Support Offices (GAPI – *Gabinetes de Apoio à Propriedade Intelectual*) emerged in 2001. The initiative was taken by INPI (*Instituto Nacional da Propriedade Industrial* – National Institute for Intellectual Property), co-financed by public funds (POE - *Programa Operacional da Economia*, 28/07/2000 - and PRIME - *Programa de Incentivos à Modernização da Economia*, 8/08/2003), within the 3rd Community Support Framework, particularly addressing the issue of technology transfer.

Given that one of the most noticeable structural weaknesses of the Portuguese economy is the virtual lack of linkages between universities and industry (Teixeira and Costa, 2006), following the creation of the GAPI network, in March 2007, the Portuguese Science and Technology Foundation (FCT) launched the University Technology Enterprise Network (UTEN), in conjunction with the IC2 Institute, The University of Texas at Austin (UTEN, 2011).

The main goal of UTEN is to build a network of highly trained professionals in science and technology transfer and commercialization. In pursuit of this vision, UTEN has provided immersive training events to develop skills and professional competence, while introducing participants to international experts and industry contacts. UTEN's new creative learning mechanisms have focused on capacity building through innovative technology transfer practices, related know-how, commercialization skills, and developing both formal and informal national and international networks. UTEN's programs and activities include International Internships, Specialized Training and Networking, Technology Commercialization, Observation and Assessment, and Institutional Building (UTEN, 2012). Formally, the UTEN network includes all the public Portuguese universities and a private one, their associated Technology Transfer Offices (TTOs), research centers and, in some cases, technology parks. It focuses on capacity building for the accelerated commercialization of Portuguese Science and Technology (S&T).

Despite the political and economic relevance of such a program, to date, an assessment of the efficiency of these TTOs has yet to be conducted and there is, consequently, no account of what may comprise its main determinants. The issue of efficiency in technology transfer, although to some extent neglected in the innovation literature, has been addressed in a few important studies. The most relevant ones (e.g., Siegel *et al*., 2003; Chapple *et al*., 2005; Siegel *et al*., 2008) employ non-parametric (DEA – Data Envelopment Analysis) and parametric (SFE – Stochastic Frontier Estimation) approaches to compute the relative efficiency of TTOs. DEA generates an efficiency frontier on the basis of individual observations (Thursby and Kemp, 2002; Curi *et al*., 2012), while SFE yields an efficiency frontier on the basis of average values (Siegel *et al*., 2003; Chapple *et al*., 2005). Relative efficiency is here estimated in terms of distance from the efficiency frontier and involves measurement of inputs (invention disclosures; total research income; number of TTO staff; external legal IP expenditure, etc.) and outputs, in terms of both monetary and physical values (number of licenses executed, invention disclosures, patent applications and the amount of industry-sponsored research and royalties received).

Most of the studies focus their analysis on more advanced countries, where U-I relations are mature and well developed, namely the USA (e.g., Thursby and Thursby, 2002; Thursby and Kemp, 2002; Siegel *et al*., 2003; Anderson *et al*., 2007), the UK (Chapple *et al*., 2005), Spain (Caldera and Debande, 2010), and France (Curi *et al*., 2012). Siegel *et al*. (2008) provide a cross-country comparison of TTOs from the USA and the UK.

The few studies that address the issue of technology transfer in Portugal do not explicitly deal with the efficiency of TTOs, focusing rather on the role of science parks and business incubators for high value added entrepreneurship (Ratinho and Henriques, 2010; Gibson and Naquin, 2011). Thus, it would be enlightening to gather evidence on the relative efficiency of TTOs in a context pervaded by weak linkages between university and industry but where policy-driven measures to foster the commercialization of academic research has been quite intensively addressed in the last ten years.

This study therefore intends to complement the research that has been conducted in the field of technology transfer (Chapple *et al*., 2005; Siegel *et al*., 2008; Curi *et al*., 2012), by comparing the efficiency of several Portuguese universities' TTOs, assessing the evolution of their efficiency in technology transfer processes in the last ten years. It will further explore the extent to which the characteristics of universities (such as the size of the university, the presence of science parks and medical schools, the number of scientific publications and accumulated patents, and public vs. private ownership) impact on the efficiency of the associated TTOs. Specifically, the main research question of the present study is: Do the characteristics of universities impact on the efficiency of the associated TTOs?

Using the Data Envelopment Analysis (DEA) approach, which is a multiple-measure evaluation tool, the performance of several organizations is evaluated over a five-year period (2007-2011) when there are multiple inputs and multiple outputs to the system. The choice of this method lies in the fact it enables performance to be characterized in terms of single measures to evaluate performance from a multiple systems perspective (Zhu, 2009). Additionally, the main determinants of TTO efficiency are econometrically assessed through panel data estimations.

The study is structured as follows. The next chapter reviews the relevant literature clarifying the key concepts (technology transfer and efficiency), providing an account of the state of the art concerning the efficiency of TTOs, and the relation between that efficiency and the characteristics of the host universities. Chapter 3 briefly describes the methodology and data gathering procedures undertaken. The empirical results are presented in Chapter 4 and, finally, the Conclusions put forward the study's main results and limitations.

2. A critical review of the literature: TTOs efficiency and its determinants

2.1. Defining the key concepts: technology transfer and efficiency

Knowledge creation by universities and its transfer to the world of business through newly commercialized technologies can decisively contribute to the creation of new business opportunities and linkages which foster the growth of new companies (Chapple *et al*., 2005).

The concept of technology transfer should be understood as a two-way flow from university to industry and vice versa, but with different degrees and forms of academic involvement (Etzkowitz, 1998): (1) the product/service/technology originates in the university but its development is undertaken by an existing firm; (2) the commercial product originates outside of the university, with academic knowledge utilized to improve the product; or (3) the university is the source of the commercial product and the academic inventor becomes directly involved in its commercialization through the establishment of a new company.

From the point of view of firms, relations with universities have traditionally been regarded primarily as a source of human capital and future employees, and secondarily as a source of knowledge that is useful to businesses (Etzkowitz, 1998). However, university-industry relationships have evolved and nowadays the issue of the 'capitalization of knowledge' has contributed to greater proximity among them (Freitas *et al*., 2013). As technological innovation becomes more strongly attached to research, both organizational and academic boundaries are broken. Consequently, there are several mechanisms, such as patents, consulting, spin-offs, publications, informal meetings, or personal exchange, which facilitate the technology transfer process between universities and industry (Bekkers and Freitas, 2008).

Goktepe (2005) proposes a classification for the generic U-I technology transfer mechanisms divided into three types: 1) technology transfer and co-development via formal research contracts (R&D agreements; R&D consortia; co-funding of research; co-supervision of PhD and MSc. theses; collaboration in national competence centers); 2) technology transfer via mobility/exchange of individuals (employment of graduates; faculty consultancy; university sabbaticals; industry scientist working at universities;

individual collaboration); and 3) technology transfer by means of casual, occasional and/or contributory means (conferences, seminars, workshops; scientific publications; popular lectures; university fairs; university open days; joint-labs; continuing education for industry (sandwich programs)).

However, there are differences in the degree to which firms are capable of using university research to their benefit. The degree of connection between universities and firms will determine if these firms are able to capture knowledge (Agrawal, 2001).

Some authors conclude that the most important knowledge transfer channels are publications (Cohen *et al*., 2002), patents (Narin *et al*., 1997) and formal collaboration (Monjon and Waelbroeck, 2003). Nevertheless, informal contacts and consulting (Cohen *et al*., 2002) are also frequently used in U-I relations.

Geuna and Muscio (2009) identify two different governance modes of university-industry interactions that currently co-exist: personal contractual interactions between university researchers and firms (Liebenau, 1985) and institutional university–industry interactions intermediated by units such as departments, university Technology Transfer Offices (TTOs) and other kinds of knowledge transfer offices (Santoro and Gopalakrishnan, 2000).

In the past few years, the issue of the efficiency of TTOs has been addressed by several authors (e.g., Siegel *et al*., 2003; Chapple *et al*., 2005; Siegel *et al*., 2008; Curi *et al*., 2012).

Efficiency can be defined and analyzed in several ways. It is useful to consider a simple production process in which a single input is used to produce a single output. The production frontier that results therefrom defines the relationship between the input and the output. This production frontier represents the maximum output achievable from each input level. The unit of analysis (e.g., TTO) is considered 'technically efficient' if it operates on that frontier or 'technically inefficient' if it falls beneath the frontier (Zhu, 2009).[1]

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[1] In some cases, it is possible to consider 'allocative efficiency', in addition to 'technical efficiency', if information on prices is available and a behavioral assumption like cost minimization or profit maximization is appropriate (Coelli et al., 2005). Allocative efficiency involves the selection of a mix of inputs (e.g. labor and capital) that produces a quantity of output at minimum cost. These two concepts, allocative and technical efficiency, combine to generate an overall economic measure (Coelli et al., 2005).

Different approaches have been used to estimate efficiency in terms of distance from the efficiency frontier. Some studies are based on the data envelopment analysis (DEA) approach (Thursby and Kemp, 2002; Anderson *et al*., 2007; Curi *et al*., 2012), allowing for a multiple-output structure. These studies involve measurement of outputs, in terms of both monetary and physical values, using the number of licenses executed, the amount of industry-sponsored research, the number of new patent applications, the number of invention disclosures and the amount of royalties received (Thursby and Kemp, 2002); licensing income, licenses and options executed, start-up companies, US patents filed and US patents issued (Anderson *et al*., 2007); number of patent applications, number of patents with submitted extensions, number of extensions required and number of software applications (Curi *et al*., 2012). Thursby and Thursby (2002) use Total Factor Productivity (a method based on the DEA approach), and define as outputs the number of licenses executed, patent applications and invention disclosures.

Siegel *et al*. (2003) and Chapple *et al*. (2005) employ the stochastic frontier estimation (SFE) approach, restricting the process of technology transfer to a single-output structure. Using one output at a time, both studies estimate two distinct frontiers (number of licenses and license income). Later, Siegel *et al*. (2008) expand their initial works by constructing a multiple-output distance function from a parametric approach, which encompasses the number of licenses, licensing income and the number of university spinouts.

Based on a rather distinct approach, using a simple linear regression analysis, Caldera and Debande (2010) estimate several differently specified models, where the outputs are measured in terms of income (from R&D contracts and licensing), number of R&D contracts, licensing agreements, and number of spin-offs.

In terms of input indicators, the most frequently used are the 'number of TTO staff' or 'TTO size' (Thursby and Thursby, 2002; Thursby and Kemp, 2002; Siegel *et al*., 2003; Chapple *et al*., 2005; Siegel *et al*. 2008; Curi *et al*., 2012), 'invention disclosures' (Siegel *et al*., 2003; Chapple *et al*., 2005; Caldera and Debande, 2010) and 'external legal IP expense' - external legal costs associated with Intellectual Property protection and commercialization (Siegel *et al*., 2003; Chapple *et al*., 2005; Siegel *et al*., 2008). Some authors choose to include the 'number of publications' (Caldera and Debande, 2010; Curi *et al*., 2012), ‘total research income’ (Chapple *et al*., 2005; Siegel *et al*., 2008) and ‘total research spending’ (Anderson *et al*., 2007). Another type of input is used by Thursby and Kemp (2002) and Siegel *et al*. (2008): ‘total faculty’ and ‘faculty quality’ rating in the PhD granting departments of the program area (biological sciences, engineering and physical sciences).

Thursby and Thursby (2002) distinguish two kinds of inputs: observable (‘number of TTO staff’, ‘federal support’, ‘faculty size’, ‘research funds’ and ‘industry-sponsored research’) and unobservable (‘faculty's propensity to disclose’ and ‘probability of invention discovery’). These authors also chose the input ‘federal support’ and added the ratio of TTO size per 100 faculty staff. In their turn, Caldera and Debande (2010) use the ‘percentage of faculty with research leave’ and the ‘average number of research leaves per faculty’.

The efficiency measure that is present in the studies that involve a DEA analysis is closer to the concept of technical efficiency - a producing unit is “technically inefficient” if it is possible to produce more output with the same inputs, or to produce the same output with fewer inputs. On the other hand, the efficiency measure that is related to SFE analysis is closer to profit efficiency. The profit frontier typifies the maximum profit achievable from production activity. Thus, producers operating on their profit frontier are labeled ‘profit efficient’ and producers operating below their profit frontier are called ‘profit inefficient’ (Kumbhakar and Lovell, 2000; Curi *et al*., 2012).

2.2. Determinants of TTOs efficiency: main hypotheses to be tested

Several characteristics of TTOs and universities have been analyzed in the literature regarding efficiency. Regarding TTOs, age/experience (e.g., Siegel *et al*., 2003; Siegel *et al*., 2008; Caldera and Debande, 2010), and size (Thursby and Kemp, 2002; Caldera and Debande, 2010; Curi *et al*., 2012) are mentioned the most often. University characteristics include variables such as the presence of science parks (Caldera and Debande, 2010 and Siegel *et al*., 2008) or medical schools (e.g., Thursby and Thursby, 2002; Chapple *et al*., 2005; Curi *et al*., 2012), the type (public versus private) (Thursby and Kemp, 2002; Curi *et al*., 2012), size (Curi *et al*., 2012), accumulated knowledge in terms of patents (Thursby and Kemp, 2002), and publications (Siegel *et al*., 2008). Regional-related factors are also likely to explain TTO efficiency, namely the region’s economic development (Chapple *et al*., 2005; Siegel *et al*., 2008; Curi *et al*., 2012), regional R&D (Chapple *et al*., 2005; Siegel *et al*., 2008; Curi *et al*., 2012), and the region's industrial context, specifically the share of high-tech businesses (Siegel *et al*., 2008).

The age/experience of TTOs has relevance on their efficiency, as TTOs with more experience in formal management of technology transfer are better prepared for this process (Siegel *et al*., 2003). This determinant takes into account possible "learning by doing" effects in the production of technology, which may consequently facilitate the transfer process. If TTOs over the years learn to focus their strategies of technology transfer on the creation of new patents or new licenses, it may be possible to expect a positive impact on their efficiency. Conti and Gaulé (2009) report that older TTOs are more experienced in the management and valorization of technology transfer, in line with results obtained by Siegel *et al*. (2003). In contrast, Caldera and Debande (2010) and Siegel *et al*. (2008) find a negative relation between the TTOs' age/experience and the output 'licensing income'. Siegel *et al*. (2008) explain their results arguing that older TTOs are less focused on licensing and, instead, place greater importance on alternative mechanisms of technology transfer, such as placement of students and sponsored research.

Regarding the output 'number of licenses', a positive relation is found by Siegel *et al*. (2003) and Caldera and Debande (2010), contrasting with the results of Chapple *et al*. (2005). However, the most significant results in this field are related to the outputs 'R&D income' and 'number of R&D contracts'. Caldera and Debande (2010) find, at the 1% significance level, a positive relation between these outputs and the TTOs' age. For the authors, this result might indicate that TTO incentives are biased in favor of maximizing the number of contracts, regardless of the flow of income generated by such contracts.

Curi *et al*. (2012) also show that older TTOs appear to have a positive effect on the efficiency of technology transfer, due to an increasing learning process, which means more professionalized TTO staff members. Therefore, we propose that:

Hypothesis 1: Older TTOs tend to be more efficient.

TTO size is also an important determinant for some authors (e.g., Caldera and Debande, 2010; Curi *et al*., 2012), who assume that in larger TTOs the staff may specialize in areas in which they have specific expertise and consequently the TTO might generate more technology transfer outcomes.

Caldera and Debande (2010) and Curi *et al*. (2012) show, at the 1% significance level, that larger TTOs present better results, with regard to the outputs 'R&D income' and 'number R&D contracts' in the first study, and efficiency levels in the case of the latter. Caldera and Debande (2010) also report a positive influence on the outputs 'number of licenses' and 'number of spin-offs' (at the 5% and 10% significance level, respectively). Although Thursby and Kemp (2002) found opposite results, we propose:

Hypothesis 2: Larger TTOs tend to be more efficient.

The presence of a science park can act as an important catalyst in fostering interaction between universities and firms located in and near the park, as well as in the creation of firms that emerge from university research (APTE, 2006). This type of infrastructure has been traditionally linked to economic growth and the creation of new companies (Castells and Hall, 1994; Phan *et al*., 2005). Thus, in a country with an abundance of science parks such as Portugal, which has more science parks than some of the more developed economies of the EU, such as France, Italy or the UK (Ratinho and Henriques, 2010), this leads us to surmise that such infrastructures may have a positive effect on TTO efficiency.

Only Caldera and Debande (2010) have obtained results regarding this matter, showing that the presence of science parks has a positive and strong influence on the number of R&D contracts in Spain (significant at the 1% level). Consequently, we posit that:

Hypothesis 3: The presence of science parks and similar infrastructures exerts a positive influence on TTO efficiency.

The determinant 'presence of a medical school' arises due to the importance of the biomedical area in technology transfer processes. Pressman (1995) reports that 60% of university licenses resulted from a biomedical invention. Thus, universities with medical schools may be more easily able to achieve good results in technology transfer processes. However, the empirical results in this regard are controversial. For instance, Thursby and Kemp (2002), and Anderson *et al*. (2007) conclude that the possibility of a medical school does not explain the variation in technology transfer efficiencies. The two studies find that at a statistically significant threshold of 5% this variable is insignificant (though it would be significant and negative at 10%). In turn, Curi *et al*.

(2012) find that the presence of a medical school slows the efficiency of French TTOs. This result can possibly be explained by excessive ‘local competition’, concentrated on the medical school and the university-related hospital, which are two legally independent entities.

Some studies explain this relationship by discriminating the various outputs. Regarding ‘licensing income’, Chapple *et al*. (2005) find a significant negative relation between the presence of a medical school and this output. In turn, Siegel *et al*. (2003) and Siegel *et al*. (2008) report a positive relation between ‘licensing income’ and the presence of a medical school. The higher levels of technical inefficiency reported by Chapple *et al*. (2005) regarding UK universities with medical schools are, in these authors’ opinion, due to differences between product markets for health care in the UK and US, since the health care market is substantially larger in the US than in the UK.

Contrary to evidence found by Thursby and Thursby (2002) for US universities, Siegel *et al*. (2008) find a positive relation between the presence of a medical school and the output ‘number of licenses’. It is also important to highlight the positive influence of this determinant on the following outputs: ‘invention disclosures’, ‘patent applications’ (Thursby and Thursby, 2002), ‘R&D income’, ‘number of R&D contracts’ (Caldera and Debande, 2010), and ‘number of startups generated’ (Siegel *et al*. 2008).

Despite this controversy, we hypothesize that the presence of a medical school could be a crucial environmental/organizational factor for achieving relative efficiency in university/industry technology transfer, seeing as these institutions offer a supportive culture for technology commercialization. Indeed, Bulut and Moschini (2009), having performed an econometric analysis of university licensing income, found that most of the profits were concentrated in universities with medical schools. Consequently, we propose that:

Hypothesis 4: Universities with medical schools tend to be associated to high efficiency TTOs.

Some literature (e.g., Thursby and Kemp, 2002; Siegel *et al*., 2003) also argues that public universities/TTOs may be less focused on university/industry technology transfer as a source of revenue and may have less flexible UITT policies than private universities, concerning startup companies and connections with other firms. Therefore, the issue of ownership (public vs. private) is particularly relevant.

All the studies that found significant evidence for the effect of this determinant (Thursby and Thursby, 2002; Thursby and Kemp, 2002; Siegel *et al.*, 2003; Caldera and Debande, 2010) conclude that public universities/TTOs have a negative effect on the 'number of licenses'. However, in relation to the outputs 'R&D income' and 'number of R&D contracts', Caldera and Debande (2010) find strong evidence (at the 1% significance level) of a positive effect in public universities in Spain.

Thus, in some countries, private universities may be more flexible and have closer ties with industry leading to better performance (Belenzon and Schankerman, 2009), but in the case of Portugal, which may be similar to the case of Spain, public universities are generally older than private ones, so it is more likely they have longer research experience and better relationships with firms, which may translate into better performance. Therefore, we propose that:

Hypothesis 5: TTOs that are associated to public universities are more efficient than those associated to private universities.

The university's size (measured, in general, by the number of researchers) is expected to positively affect the performance of TTOs. Colombo *et al.* (2010) argue that the size of the university research staff determines the amount of knowledge that industry may have access to. Thus, the greater the number of scientists within a university, the more knowledge and skills are available to be transferred to the companies (O'Shea *et al.*, 2005). Thereby, larger universities are expected to produce more research. Consequently:

Hypothesis 6: TTOs that are associated to larger universities tend to be more efficient.

The connections between universities and industry are also influenced by intellectual property rights, such as patents, which play a crucial role in boosting innovation. Thus, the contribution of universities in this field may depend on the commercial orientation of university research (Colombo *et al.*, 2010). Greater commercial orientation may facilitate the incorporation of the knowledge produced by universities on the part of local firms. The tendency of a university to conduct commercially-oriented research should increase the likelihood of discovering technologies and producing knowledge that have commercial value (Di Gregorio and Shane, 2003). Therefore, we propose:

Hypothesis 7: A higher number of accumulated patents by a university has a positive impact on TTO efficiency.

University policies are important determinants of the technology transfer process, and universities with internal rules regulating the participation of researchers in technology transfer perform better than universities without such rules (Caldera and Debande, 2010). Thereby, the knowledge pool that is produced by the university is essential in this process and scientific publications often contain novelties that can be exploited by companies as some form of 'raw material' (Curi *et al*., 2012). Therefore:

Hypothesis 8: The number of scientific publications and R&D excellence centers of a university exerts a positive influence on TTO efficiency.

Finally, the relationships between universities and the regions' development and technological competencies may also be a determinant of TTO efficiency, since it is plausible that universities are more likely to license technology to firms located nearby, trying to create collaborative relationships. Some authors focus on the importance of location and regional spillovers (e.g., Owen-Smith *et al*., 2002; Broström *et al*., 2009) and argue that regional clusters could be an important vehicle to attract talented researchers, high-quality students and increase shares of R&D funding, in addition to for-profit companies dedicated to the commercialization of new technologies.

All the studies that have focused on the influence of regional R&D (Siegel *et al*., 2003; Chapple *et al*., 2005; Siegel *et al*., 2008; Curi *et al*., 2012) reached the same conclusions: universities located in regions with higher levels of R&D are more efficient in technological transfer activities. Furthermore, it was found that regional Gross Domestic Product (GDP) per capita has a positive effect on TTOs in generating license income, in the case of TTOs in the UK, and on new licenses for TTOs in both the UK and US (Siegel *et al*., 2003; Siegel *et al*., 2008). In the case of French TTOs, it was found that the scale economies related to university size and the local intensity of industry R&D contribute decisively to the successful operation of TTOs (Curi *et al*., 2012). Therefore:

Hypothesis 9: Regional economic development exerts a positive influence on TTO efficiency.

Hypothesis 10: Regional industrial basis (namely the share of new high- and medium-tech firms) exerts a positive influence on TTO efficiency.

3. Methodology

3.1. Technology transfer process: main phases

Generally, the technology transfer process is seen as a sequence of three or four main phases (see Figure 1). Each phase has its importance in the enhancement and development of the business idea. Upstream, the first stage involves an ‘Invention Disclosure’, a confidential document written usually by a scientist used to determine whether patent protection should be sought for the described invention. If the disclosure is accepted, a patent attorney is assigned to prepare a patent application. The TTO is notified of the intention to protect an idea or technology, which starts the process of optimizing R&D results. Informing the TTO about the invention serves to obtain preliminary knowledge about the invention, its development and market potential, so as to answer the following questions: Is the technology new? (novelty principle); Is it inventive? Is the technology likely to be produced industrially?

If the invention meets the requirements of patentability and if the market potential is interesting, the TTO asks the inventor to start the patenting process. As a rule, the protection process begins, in the Portuguese case, with the filing of a national patent at the INPI (*Instituto Nacional da Propriedade Industrial*), taking advantage of a priority period of 12 months before deciding the extent, or not, to which the patent can be applied to other countries.

Patents can then be commercially explored through licenses or directly by creating a new business firm, the so-called academic spin-offs or start-ups.

The development of a start-up/spin-off implies three major steps: 1) Pre-incubation; 2) Incubation; 3) Acceleration. At the stage of pre-incubation, the entrepreneurs, with the help of a TTO/Science Park, develop their plan and business model, do the necessary market validations and develop the prototypes/case studies of their products and services. At the end of this stage, entrepreneurs have a very clear view of the technology, the economic and strategic variables associated to their project and its viability. During incubation, companies work actively in the process of entry into markets by raising its first customers, while continuing development and improvement of its solutions. In addition, companies will have access to all programs and advanced services specifically designed to support the growth of companies located in the park. Finally, in the acceleration phase, it is expected that the company is able to move to its own space, preferably similar in structure to that of the S&T Park, which will continue to offer a favorable environment to the continuous process of development and growth.

Downstream, option agreements and cooperation with companies have to do with the identification of potential licensors of technology based on factors such as production capacity and distribution channels, compatibility with lines of existing products / services and the ability to support the product on the market. The negotiation process is conducted so as to safeguard the interests of the university and entities involved in sharing the risk and expected benefits.

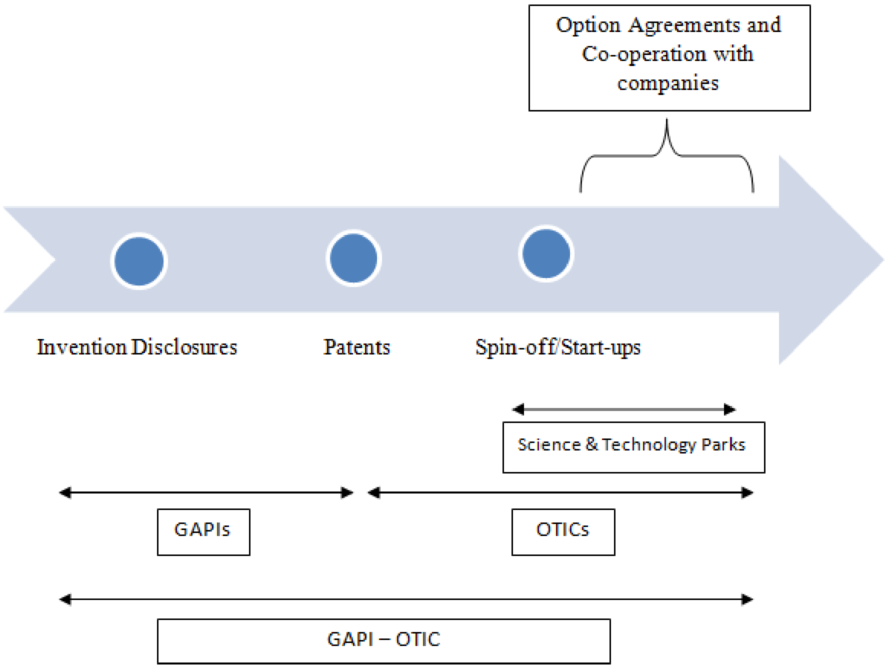


Figure 1: Technology transfer phases and TTOs positioning

Source: Author's compilation

3.2. Describing the target population

Our target population includes different types of TTOs: GAPIs (*Gabinetes de Apoio à Promoção da Propriedade Industrial*), OTICs (*Oficinas de Transferência de Tecnologia e Conhecimento*), and integrated units, GAPI-OTICs, including some S&T Parks which perform technology transfer activities.

GAPIs - *Gabinetes de Apoio à Promoção da Propriedade Industrial*

GAPIs were established within universities, technology centers and business associations, with the aim of promoting the use of intellectual property (Cartaxo and Godinho, 2012) and were an initiative of the Portuguese Patent and Trademark Office (INPI, see www.inpi.pt). GAPIs were first established in 2001, in three phases (2001, 2003 and 2006). Almost half of all the GAPIs created since 2001 were established within universities (10 of a total of 22).

This national network of offices includes 11 TTOs of the UTEN network: UPETT-UNL (*Unidade de Promoção do Empreendedorismo e Transferência de Tecnologia – Universidade Nova de Lisboa*); UPIN (*Universidade do Porto Inovação*); TT@IST (*Área de Transferência de Tecnologia – Instituto Superior Técnico*); VCI-IPN (*Valorização do Conhecimento e Inovação – Instituto Pedro Nunes*); TecMinho (*Universidade do Minho*); CRIA (*Universidade do Algarve*); Audax-ISCTE-IUL (*Instituto Universitário de Lisboa*); UL-Inovar (*Universidade de Lisboa*); GAPPI-UBI (*Universidade da Beira Interior*); GAPI-OTIC.UTAD (*Universidade de Trás-os-Montes e Alto Douro*); UATEC (*Universidade de Aveiro*).

Generally, GAPIs focus on the more upstream phases of the technology transfer process, namely invention disclosures and patents. They are characterized by a relatively high output in what concerns the number of invention disclosures that are reported by the associated universities and patents. However, some of these TTOs also present a good performance in terms of spin-off/start-up companies and R&D agreements. Summing up, the positioning of GAPIs is further upstream in the technology transfer process.

OTICs - *Oficinas de Transferência de Tecnologia e Conhecimento*

OTICs are "entities mediating knowledge and technology, in order to identify and promote the transfer of innovative ideas and concepts of the entities from the Scientific and Technological System to business" (Godinho *et al*., 2008) and were established in 2006 by a government organization, the Innovation Agency (AdI, see www.adi.pt). OTICs have been exclusively implemented in higher education institutions, both in universities and in polytechnic institutes. The activities developed by GAPIs and the OTICs are mostly complementary, but their goals are often partially overlapping (Cartaxo and Godinho, 2012). In a few universities, GAPIs and OTICs have merged into an integrated organizational framework, GAPI-OTIC. Setting up these organizations has been perceived as a necessary step to provide the proper context for university patenting and technology transfer (Godinho *et al*., 2008).

This network includes 5 TTOs of the UTEN network: OTIC-IPP (*Oficina de Transferência de Tecnologia e Conhecimento do Instituto Politécnico do Porto*); OTIC-UTL (*Universidade Técnica de Lisboa*); OTIC-TeCMU (*Universidade da Madeira*); TCT-OTIC.UCP (*Universidade Católica Portuguesa*); DPI-OTIC.UE (*Divisão de Projetos e Informação – Universidade de Évora*).

Normally, the positioning of the OTICs is more downstream in the technology transfer process, focusing mostly on patenting and on the creation of spin-offs and start-ups.

GAPIs-OTICs and other integrated units

Other technology transfer units are integrated units and include Inovisa-UTL (*Universidade Técnica de Lisboa*) and DITS-UC (*Divisão de Inovação e Transferências do Saber – Universidade de Coimbra*). Both have a more downstream position, directing their activity to research agreements and spin-offs/start-ups. Hence, we have classified these two types of TTO as OTICs.

Some of these TTOs, regardless of their classification, have a very comprehensive positioning, whose activity covers the entire process of technology transfer – TecMinho, GAPI-OTIC.UTAD and UATEC – and thus we have opted to define them as GAPIs-OTICs.

Geographically (cf. Figure 2), the units that are members of the UTEN network, despite being located throughout Portugal, tend to be concentrated around university campuses, and are thus relatively more concentrated on the coastal areas and in urban centers.

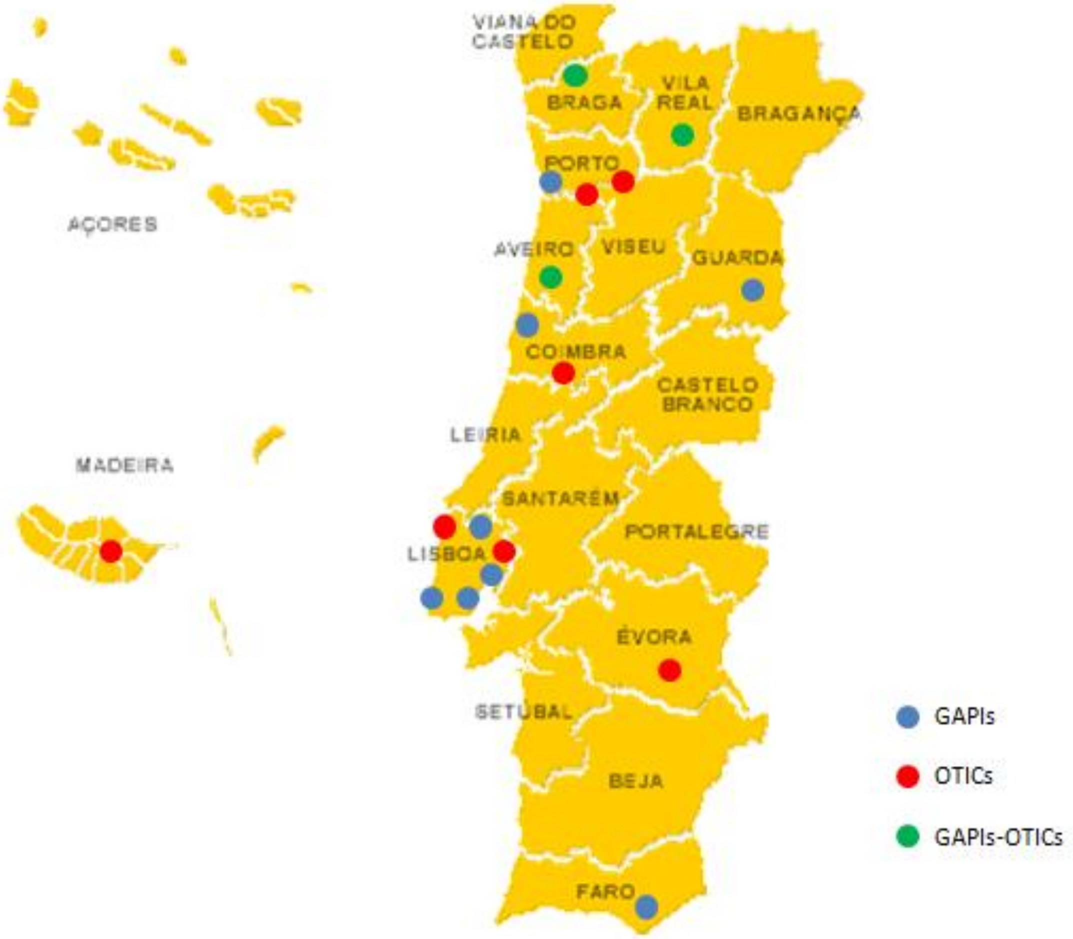


Figure 2: Regional location of TTOs
Source: Author's compilation

3.3. Data gathering process

Given the research question of the present study: Do the characteristics of universities impact on the efficiency of the associated TTOs?, the methodology employed involves two main phases. In the first phase, the efficiency of TTOs is computed on the basis of Data Envelopment Analysis (DEA). In a second phase, and in order to assess which factors explain TTO efficiency, more specifically, which university characteristics affect TTO efficiency, an econometric model is used to provide a quantitative/explanatory assessment of the impact of university characteristics on the efficiency of the associated TTOs.

The description of the technology transfer process, reported in this section, served to identify the appropriate set of inputs and outputs to be included in the efficiency analysis. Since the TTOs selected cover all the phases of the process, we decided to include outputs that reflect these phases.

Therefore, as output measures we include: invention disclosures (number of invention disclosures reported by the institution to the office), priority filings (new patent applications filed by the office for the institution) patents granted (number of patents granted to the institution through the TTO), active patents (number of accumulated patents by the university), licenses executed (number of licenses, option agreements, and assignments executed by the office), license income (total amount of license income (in Euros) received by the institution, through the TTO, from its intellectual property - patents, software, material transfer agreements, confidentiality agreements, etc.), research agreements (number of research and development agreements executed between the institution and companies through the TTO), start-ups established (number of start-ups and spin-offs established) and active start-ups (accumulated start-ups and spin-offs).

Based on the literature, the input measures selected are TTO size (office collaborators, in full-time equivalents, who are involved in technology transfer services/activities) and the TTO's total expenditure (in Euros).

A questionnaire was selected as the main data collection method. The questions formulated were intended to determine the values of several variables (inputs and outputs) used in the analysis of efficiency. The information collected relates to 2007, 2008, 2009, 2010 and 2011. The sample contains data from 18 Portuguese TTOs and was gathered during the months of March and April 2013.

The questionnaire included the following questions, listed in Table 1, according to the input and output variables.

Table 1: Input and output variables for computing TTOs efficiency

Input/ Output	Variables	Survey questions
Inputs	TTO staff	How many collaborators (in full-time equivalents) in your office are involved in technology transfer services/activities?
	Total expenditure	What is the total expenditures (in Euros) of your technology transfer office?
Outputs	Invention Disclosures	How many invention disclosures were reported by your institution to your office?
	Patents	How many new patent applications (priority filings) did your office file for your institution?
		How many patents were granted to your institution, through your TTO?
		What is your total number of active patents at the end of…
	Licenses	How many licenses, option agreements, and assignments were executed by your office?
		How many of these licenses and option agreements were granted?
		What was the total amount of license income (in Euros) received by your institution, through your TTO, from its intellectual property (patents, software, material transfer agreements, confidentiality agreements etc.)? Please include license issue fees, annual fees, option fees, etc. plus milestone, termination, and cash-in payments.
	Research Agreements	How many research and development agreements were executed through your TTO between your institution and companies?
	Spin-off/Start-ups	Number of spin-off/start-up companies established.
		Total number of active spin-off/start-up companies at end of…

3.4. Method for estimating TTOs efficiency

3.4.1. Choice between DEA vs SFE

Different methods have been used to evaluate the efficiency of TTOs. Some authors prefer to use the Stochastic Frontier Estimation approach (SFE), restricting the process to a single-output structure (Siegel *et al.*, 2003; Chapple *et al.*, 2005), whereas others employ the DEA, which enables a multiple-output structure (Thursby and Kemp, 2002; Anderson *et al.*, 2012; Curi *et al.*, 2012). In the case of a single-output structure, the output is measured by the number of units produced (data on value of production or sales/income are also available). The multiple-output structure it is used when it is necessary to analyze several products/outputs and the output quantities are available (Coelli *et al.*, 2005).

SFE is a parametric approach developed by Aigner *et al*. (1977) and Meeusen and Van den Broeck (1977). This method generates a production (or cost) frontier with a stochastic error term that consists of two components: a conventional random error ('white noise') and a term that represents deviations from the frontier, or relative inefficiency. SFE allows for statistical inference, but requires restrictive functional form and distributional assumptions. It is an alternative approach to the estimation of frontier functions using econometric techniques and has advantages over DEA when data noise is a problem. The model defined in SFE is called a 'stochastic frontier production function' since the output values are bounded from above by the stochastic (i.e., random) variable. The random error can be positive or negative and so the stochastic frontier outputs vary around the deterministic part of the model (Coelli *et al.*, 2005).

DEA is a non-parametric estimation technique, a mathematical programming approach that does not require the specification of a functional form for the production function. It is used when there are multiple outputs and when meaningful aggregation is not possible. DEA produces an efficiency rating or score for each unit of analysis (TTO or University for example) by first determining the set of units which exhibit "best practice". These units are said to form the frontier that relates outputs and inputs. Therefore, for each unit in the sample, DEA determines whether it lies on the frontier (exhibits best practice) or, if not, how "far" from the frontier it lies. Units that lie on the surface are termed efficient and those not on the surface are said to be inefficient (Zhu, 2009). The main limitations of this method are its deterministic nature, since all distances from the efficient frontier are assumed to be inefficiency, as well as its biased estimation. For this reason, DEA models are highly sensitive to outliers.

Both DEA and SFE models have advantages and disadvantages, so they should be seen as complements, not substitutes (Coelli *et al.*, 2005). Given that we intend to evaluate the performance of several organizations (TTOs) in their process of technology transfer, which is characterized by multiple inputs and outputs, the DEA method is more appropriate. This approach allows us to work with a small number of observations, as opposed to SFE that requires a larger sample.

Specifying the procedure to measure efficiency, we use, in line with the relevant literature (e.g., Siegel *et al.*, 2003; Chapple *et al.*, 2005; Curi *et al*., 2012), several types of inputs, namely the number of publications on universities, invention disclosures, TTO size, total research income, number of TTO staff and external legal IP expenditure. Then, these inputs are related with the outputs of the system: number of patents, number of spin-offs, number of licenses and licensing income.

3.4.2. DEA method in detail

The DEA (Data Envelopment Analysis) method was originally developed by Charnes, Cooper and Rhodes in 1978. It serves to compare the relative efficiency of a certain number of productive units that perform similar activities, but differ in terms of amounts of resources (inputs) and products (outputs). In this method, the productive unit is called Decision-Making Unit (DMU).

DEA is a method of extreme points and compares each production unit with the other units, producing a measure of relative efficiency. It uses linear programming techniques enabling the incorporation of multiple inputs and multiple outputs.[2] Thereby, this relative efficiency accounts for the ratio between unique virtual outputs and inputs. As can be seen in the following equation, y_{rj} represents the output r of unit j, x_{ij} represents the input i of unit j, and v_i and u_r represent respectively the weights of each input i and each output r.

$$Efficiency_j = \frac{\sum_{r=1}^{s} u_r \, y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}}$$

In this way, relating the inputs with the outputs, it is possible to create an "ideal unit" through optimization. The function above sets a limit or "frontier" on the scope of possibilities observed. Thus, the production frontier determines the maximum output that can be produced by a given set of inputs (Figure 3). DEA produces an efficiency rating or score for each TTO by first determining the set of TTOs which exhibit 'best practice'. For each TTO in our sample, DEA determines whether it lies on the frontier (best practice) or, if not, how 'far' from the frontier it lies. Units that lie on the surface are termed efficient and those not on the surface are said to be inefficient. In Figure 3, the line linking TTOs 1-4 is the best practice frontier. From the standpoint of efficiency, none of these TTOs dominates the others; each successively uses more input and produces more output. TTOs 5 and 6, on the other hand, are dominated by the others.

[2] Farrell's (1957) quantification of technical efficiency compares a single output with a single input.

For instance, TTO 2 uses less input and produces more output than TTO 5. Both 5 and 6 lie below the efficient frontier, and to measure inefficiency they are compared to the nearest facets linking efficient TTOs.

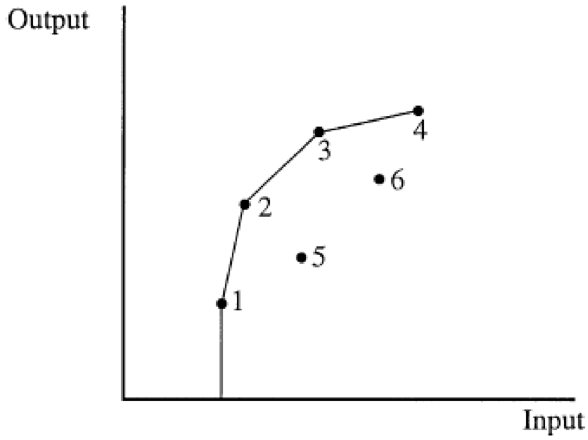


Figure 3: DEA production frontier.
Source: Thursby and Kemp (2002)

In frontier models, such as the DEA, efficiency indicates the best practice production of DMUs. Thereby, the model determines whether a DMU is efficient or not by the distance between the position of a DMU and the production efficiency frontier. Deviations from the frontier represent a measure of relative inefficiency to the optimum that could be achieved.

There are two basic models in the DEA literature: the CCR model (Charnes *et al*., 1978) or CRS – *Constant returns to scale,* and the BCC model (Banker *et al*., 1984) or VRS – *Variable returns to scale*.

The main difference between the two models is that the CCR model considers constant returns to scale, i.e., it is assumed that any variation in the inputs will produce a proportional variation in the output, while the BCC model considers variable returns to scale, since the axiom of proportionality between inputs and outputs is replaced by the axiom of convexity. Both models serve to define the orientation. The model is *input-oriented* when there is an increase in efficiency by minimizing the inputs, keeping the outputs constant. On the other hand, the model is called *output-oriented* when the purpose is to maximize the outputs without changing the inputs.

In the CCR model, the generalization of the measure of technical efficiency is done by creating and using a single “virtual” output, which represents the set of desired outputs, and a single “virtual” input, which represents the set of inputs used to produce the outputs. The CCR model – input oriented – has the following form:

$$\max_{\mathrm{U_i,V_k}} h_0 \quad = \quad \frac{\sum_{i=1}^{t} U_I Y_{i0}}{\sum_{k=1}^{m} V_k X_{k0}}$$

Subject to,

$$\frac{\sum_{i=1}^{t} U_i Y_{ij}}{\sum_{k=1}^{m} V_k X_{kj}} \leq 1$$

Where, $i = 1, \dots, t$; $k = 1, \dots, m$; $j = 1, \dots, n$; $U_i, V_k \geq 0, \ \forall\, i, k$

Alternatively, the output-oriented form is:

$$\min_{\mathrm{U_i,V_k}} h'_0 \quad = \quad \frac{\sum_{k=1}^{m} V_k X_{k0}}{\sum_{i=1}^{t} U_i Y_{i0}}$$

Subject to,

$$\frac{\sum_{k=1}^{m} V_k X_{kj}}{\sum_{i=1}^{t} U_i Y_{ij}} \geq 1$$

Where, $i = 1, \dots, t$; $k = 1, \dots, m$; $j = 1, \dots, n$; $U_i, V_k \geq 0, \ \forall\, i, k$

The **BCC** model allows DMUs to have increasing returns to scale or decreasing returns to scale.

BCC model – input-oriented:

$$\max_{\mathrm{U_i,V_k}} h_0 \quad = \quad \frac{\sum_{i=1}^{t} U_I Y_{i0} - U_*}{\sum_{k=1}^{m} V_k X_{k0}}$$

Subject to,

$$\frac{\sum_{i=1}^{t} U_i Y_{ij} - U_*}{\sum_{k=1}^{m} V_k X_{kj}} \leq 1$$

Where, $i = 1, \dots, t$; $k = 1, \dots, m$; $j = 1, \dots, n$; $U_i, V_k \geq 0, \ \forall\, i, k\ U_* \in \Re$

BCC model – output-oriented:

$$\min_{U_i, V_k} h'_0 = \frac{\sum_{k=1}^{m} V_k X_{k0} - V_*}{\sum_{i=1}^{t} U_i Y_{i0}}$$

Subject to,

$$\frac{\sum_{k=1}^{m} V_k X_{kj} - V_*}{\sum_{i=1}^{t} U_i Y_{ij}} \geq 1$$

Where, $i = 1, \dots, t; \; k = 1, \dots, m; \; j = 1, \dots, n; \; U_i, V_k \geq 0, \;\; \forall\, i, k \;\, V_* \in \Re$

In our computations, we decided to use CRS model (*Constant returns to scale)* – input-oriented.[3]

3.4.3. Output sensibility analysis and the choice of outputs for the efficiency metrics

Since relations between the various outputs at distinct stages of the technology transfer process of Portuguese TTOs during the period of analysis (2007-2011) have been different, we decided, before performing the efficiency analysis, to conduct a brief sensitivity exercise of the TTOs' outputs by years and by phases of the technology transfer process.[4]

Over the period in analysis, there has been a strong relation every year between the outputs 'Invention disclosures' and 'Priority filings'. More specifically, the efficiency of TTOs with respect to the output 'invention disclosures' is correlated with the efficiency associated to the output 'priority filings'. DMUs with more invention disclosures reported by the university have, on average, a greater propensity for new patent applications (priority filings).

In the first year of analysis (2007), we observe a positive (cor)relation between four groups of outputs: 'invention disclosures', 'patents', 'licenses' and 'start-ups'. It is also possible to conclude that the output 'priority filings' is related to 'patents' and 'licenses'. The variable 'research agreements' is only related with 'licenses executed' and the global values of efficiency for that year (which include two inputs and all possible outputs) are congruent with the results for 'licenses', 'research agreements' and 'start-ups'.

[3] Software: EMS (Efficiency Measurement System) - version 1.3
[4] Software: IBM SPSS Statistics – version 21

In 2008 and 2009 the results are very similar. There is a clear association between three groups of outputs: ‘invention disclosures’, ‘patents’ and ‘start-ups’. In contrast with 2007, ‘priority filings’ are related with ‘start-ups’. In turn, ‘research agreements’ and ‘licenses’ do not show any relation with other outputs and the global values are only congruent with ‘licenses executed’ (2008) and ‘research agreements’ (2009).

In the following years, it is possible to identify, in 2010, a (cor)relation between ‘invention disclosures’, ‘licenses’ and ‘research agreements’, and, in 2011, between ‘invention disclosures’ and ‘licenses’. ‘Patents’ are related with ‘priority filings’ in 2010 and with ‘start-ups’ in 2011. ‘Licenses’ are also related with ‘research agreements’ in 2011 and the global values to this year are congruent with ‘priority filings’, ‘patents granted’, ‘licenses’ and ‘start-ups’.

After this ‘sensitivity’ exercise, we computed the efficiency metrics. Based on this exercise, we decided that the most appropriate way to get to the efficiency values for each TTO was to create several models of efficiency, each one with different outputs.

The first model (Model 1) uses the outputs ‘invention disclosures’ and ‘priority filings’ to estimate the values of efficiency, since there is a high correlation/association between these two components. The second model (Model 2) encompasses the outputs related to patents: ‘patents granted’ and ‘active patents’. Model 3 includes the outputs: ‘licenses, option agreements, and assignments executed’ and ‘license income’. Model 4 deals only with the output ‘research agreements’ and Model 5 with ‘spin-off/start-up companies established’ and ‘active spin-off/start-up companies’. There is also a Global Model (Model 6) that aggregates all of these outputs.

For all these models we included two inputs in the efficiency computations, ‘TTO staff’ and ‘total expenditure of TTO’.

3.5. Econometric approach for assessing the determinants of TTOs efficiency: panel data estimation

3.5.1. Rationality for using panel data models

Given that we have information on the efficiency levels of the 18 TTOs over a five-year span (2007-2011), panel data was the natural choice for the econometric specification and estimation.

The econometric specification is given by the following model:

$$Eff_{it} = a_i + \beta_1 \boldsymbol{TTO}_{it} + \beta_2 \boldsymbol{Univ}_{it} + \beta_3 \boldsymbol{Reg}_{it} + u_{it}$$

Where i (=1, …, 18) refers to the TTO and t (=2007, …, 2011) to time. **TTO** is a vector that includes variables respecting the TTOs' characteristics, most notably, age and size. **Univ** is a vector that includes university characteristics namely, the presence of a science park, presence of a medical school, type of university (public versus private), size of the university, accumulated patents, and scientific publications. Finally, **Reg** includes variables regarding the regions' characteristics such as their economic development and their industrial basis. u_{it} is the random error.

In the estimation of the panel specifications we use fixed effects (FE) models as TTOs are heterogeneous entities and this heterogeneity is captured in the constant, which is different from individual to individual.

The constant part a_i is different for each individual, capturing differences invariant in time (e.g., organizational structure and other characteristics that do not vary in the short term). A particularity of our estimation is that due to the shortage of observations we needed to aggregate some TTOs according to the similarity of slopes. Therefore, our final estimations are not a truly fixed effects model in the sense that each unit/TTO has a different slope but some TTOs are grouped and thus the final specification has a number of slopes lower than 18.

3.5.2. Description of variables-proxies and study's hypotheses

The hypotheses to be tested are divided in three main categories: TTO characteristics, Regional context and University characteristics.

The TTO characteristics are analyzed through Hypothesis 1 – *Older TTOs tend to be more efficient* – and Hypothesis 2 – *Larger TTOs tend to be more efficient*. Thus, we present the values of these two variables considering the age of the TTO (in years) and the size of the TTO measured by the number of office collaborators, in full-time equivalents, who are involved in technology transfer services/activities.

In the category 'University characteristics' we chose to include three dummy variables corresponding to Hypothesis 3: *The presence of a science park and similar* *infrastructures exerts a positive influence on TTO efficiency* – Hypothesis 4: *Universities with medical schools tend to be associated to high efficiency TTOs* – and Hypothesis 5: *TTOs that are associated to public universities are more efficient than those associated to private universities.* These dummy variables assume the value 1 when, respectively there is a science park, medical school or when the university is public.

In this category, there are three additional hypotheses to be tested: Hypothesis 6*: TTOs that are associated to larger universities tend to be more efficient* – Hypothesis 7: *A higher number of accumulated patents by a university has a positive impact on TTO efficiency* –, and Hypothesis 8: *The number of scientific publications of a university exerts a positive influence on TTO efficiency.*

The variable-proxy chosen for Hypothesis 6 is the university's size, measured by the number of teaching and research staff. As for Hypothesis 7, the variable is the university's number of accumulated patents (total number of active patents – Portuguese, PCT, EPO, USPTO and others - at the end of 2007, 2008, 2009, 2010 and 2011) and, for Hypothesis 8, two variables-proxies are included: scientific pool of knowledge (number of indexed papers on Web of Science per researcher for the period between the years 2007 and 2011) and the university's R&D centers classified as excellent by official authorities (proportion of research units with a classification of "very good" or "excellent" by FCT – *Fundação para a Ciêcia e Tecnologia, Ministério da Educação e Ciência*).

Regional variables are related to Hypothesis 9 - *Regional economic development exerts a positive influence on TTO efficiency* – and Hypothesis 10 - *Regional industrial basis exerts a positive influence on TTO efficiency*. To test Hypothesis 9 we use the indicator municipal purchasing power index (100=Portugal). For Hypothesis 10 two indicators are used: weight of manufacturing industry firms in total forms and weight of new high- and medium-tech firms in total new firms established (these two variables are referred to on a NUTS III territorial basis).

4. Empirical results

4.1. Descriptive and exploratory analyses of TTOs efficiency

4.1.1. Dynamics of TTOs efficiency: overall and by each phase of the technology transfer process

Given that the relative efficiency varies from stage to stage within the technology transfer process, it is advisable to analyze its different stages.

The mean of the overall relative efficiency reached 63.4% in 2007, increasing to 69.6% in 2011 (see Figure 3). Thus, over the period in analysis Portuguese TTOs managed to improve their overall performance.

Analyzing the distinct stages of the technology transfer process (cf. Figure 3), we find that the relative performances are quite differentiated, higher for the more downstream stages (namely research agreements and spin-offs/start-ups established) than for upstream ones (invention disclosures, patents granted or licenses), especially in the beginning of the period. Interestingly, the upstream stages, most notably invention disclosures and patents, are the ones whose relative efficiency increased more over the period. This may in part be explained by the fact that over the period in analysis, TTOs received substantial support in terms of training, awareness workshops and international internships on the matters related to intellectual property rights in general and patenting in particular through the UTEN program. The impact of these training actions and workshops are not yet visible in more downstream stages, namely license income, research agreement and spin-off activities, which show a negative trend in terms of relative efficiency over the period. This, however, indicates that continuous efforts should be put into invention disclosure and patents, as these stages feed the downstream ones, and additional, purposeful measures should be conceived to more directly improve the stage of technology commercialization, through licenses, agreements and generation of new technology-based firms.

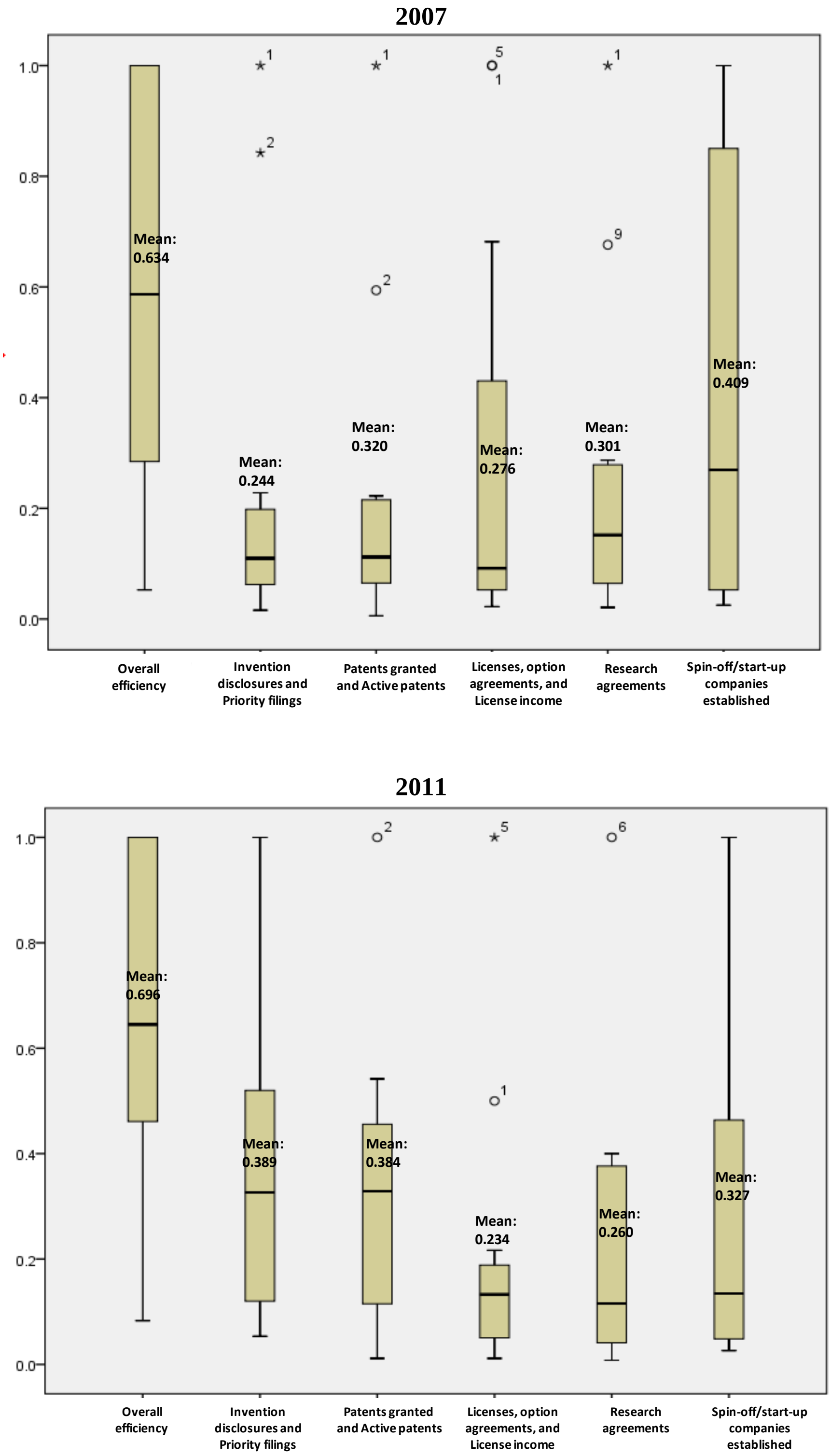


Figure 3: Box plots of TTO relative efficiency in 2007 and 2011: overall and by stages in the technology transference process

Note: The box plots produced consist of the most extreme values in the data set (maximum and minimum values), the lower and upper quartiles, and the median (the bold line). The spacings between the different parts of the box indicate the degree of dispersion (spread) of the variables. The individual values shown represent the outliers.

Source: Author's computations based on data gathered directly from 18 Portuguese TTOs.

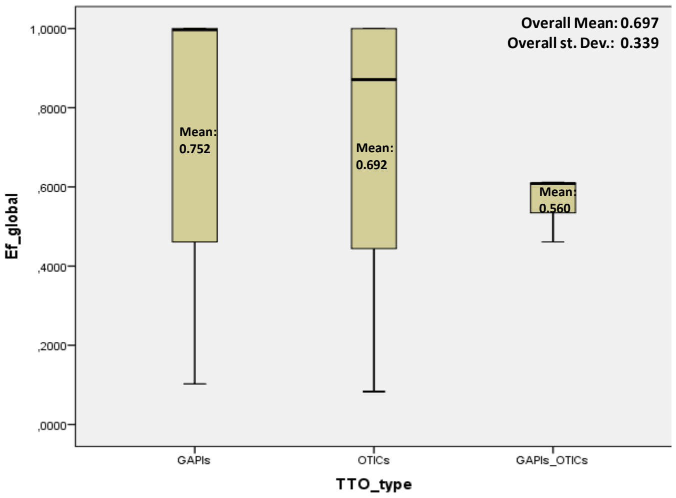
Figure 4 presents the relative efficiency in 2011 by type of TTOs, dividing them into the three main groups mentioned earlier: GAPIs, OTICs and GAPIs-OTICs.

The results of the Global Model indicate that, in general, the GAPIs are the most efficient (Mean=75.2%), followed by the OTICs (Mean=69.2%) and the GAPIs-OTICs (Mean=56.0%). In Models 1 ('Invention disclosures and priority filings') and 2 ('Patents granted and active patents'), the GAPIs continue to be the most efficient units, as would be expected, since these type of TTO tends to direct their activity towards the upstream stages of the technology transfer process.

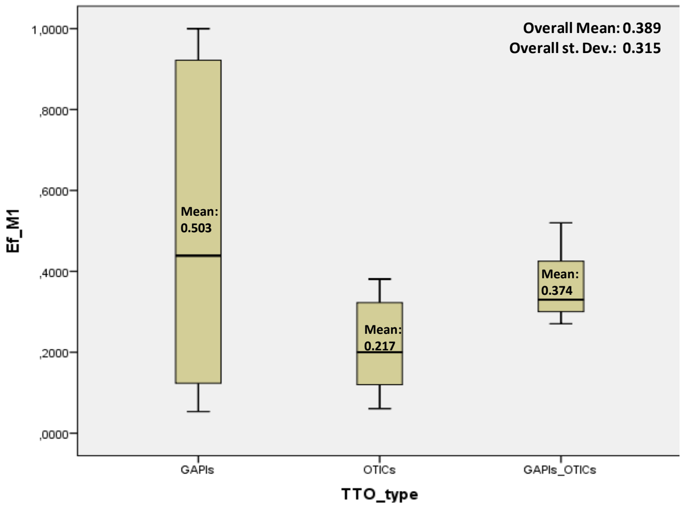
In Models 3 ('Licenses, option agreements, assignments executed and license income') and 4 ('Research agreements'), the overall means are very low (23.4% and 26.0%), which suggests that TTOs are not very focused on these two stages, so there is plenty of room to improve performance here.

The results of Model 5 ('Spin-off/start-up companies established') show that in the OTICs are the most efficient (Mean=42.3%). Typically, this type of TTO is positioned further downstream in the technology transfer process, hence their greater efficiency in supporting the creation of academic start-ups. Integrated TTOs (GAPIs-OTICs) are very similar but present rather low efficiency levels in this stage of the technology transfer process.

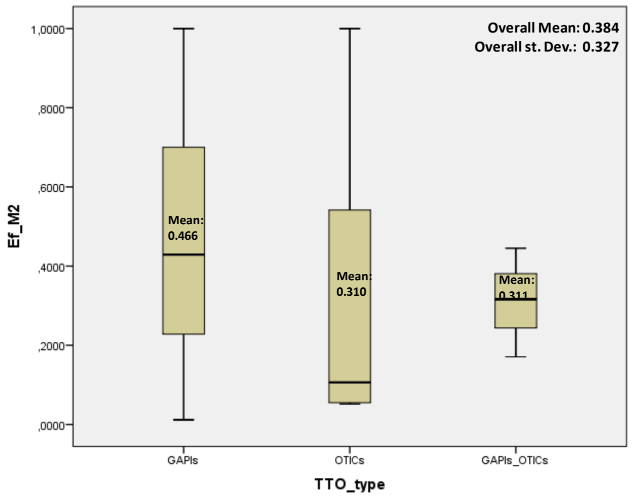
The schemes of Figure 5 reveal the dynamics of TTO efficiency and the positioning of each unit, taking into account the initial value (2007) and the final value (2011) of the efficiency of each TTO. These schemes do not represent the variations that occur during this period, only the direction of the evolution of efficiency (positive marked in green or negative marked in red). Regarding the overall efficiency (1st scheme in Figure 5), the dynamic is rather positive with only four (out of 18) TTOs loosing efficiency over the period in analysis, eight TTOs became more efficient and the remaining maintained their efficiency values at the maximum (100%). Analyzing the other schemes, we found that the TTOs gained efficiency especially in the most upstream stages of the technology transfer process – invention disclosures and priority filings. The policies aimed at fostering IP awareness and output put forward by the Portuguese authorities in the first half of the 2000s (Cartaxo and Godino, 2012) as well as the training/internships and workshop activities promoted by UTEN in recent years are likely to have a contribution to this dynamic.



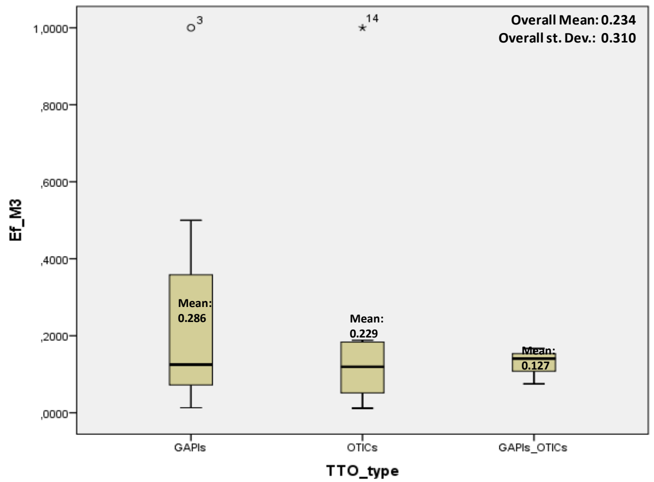
Global Model



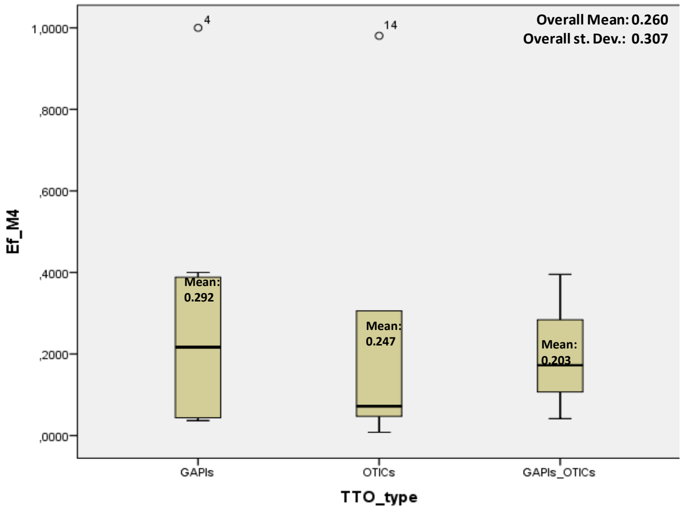
Model 1: Invention disclosures and Priority filings



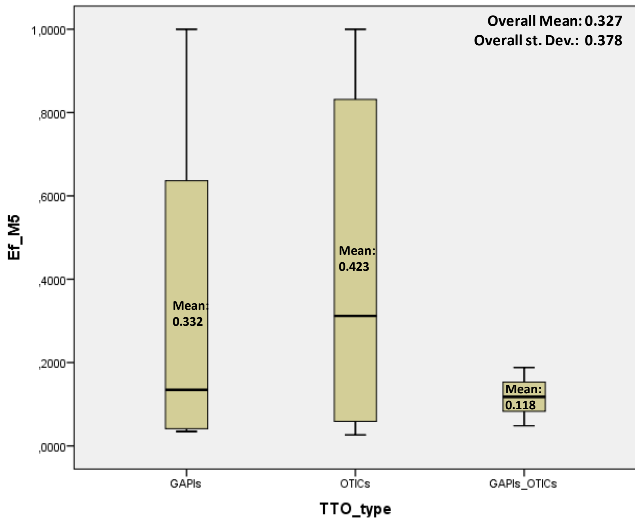
Model 2: Patents granted and Active patents



Model 3: Licenses, option agreements, and assignments executed and License income



Model 4: Research agreements



Model 5: Spin-off/start-up companies established

Figure 4: TTO relative efficiency by type of TTO (2011)

Source: Author's computations based on data gathered directly from 18 Portuguese TTOs.

In contrast, in the most downstream stages – spin-off/start-up companies established – the results are not so encouraging: nine TTOs lost efficiency and just four improved their performance.

At the intermediate stages of the technology transfer process (patents, licenses and research agreements) the results are more ambiguous, with a similar number of TTOs improving and worsening their efficiency over the period in analysis. Additionally, the improvements occurred at very low levels of efficiency and are in general small, whereas the decreases in efficiency are much more pronounced – see particularly patent granted and active patents and research agreement schemes.

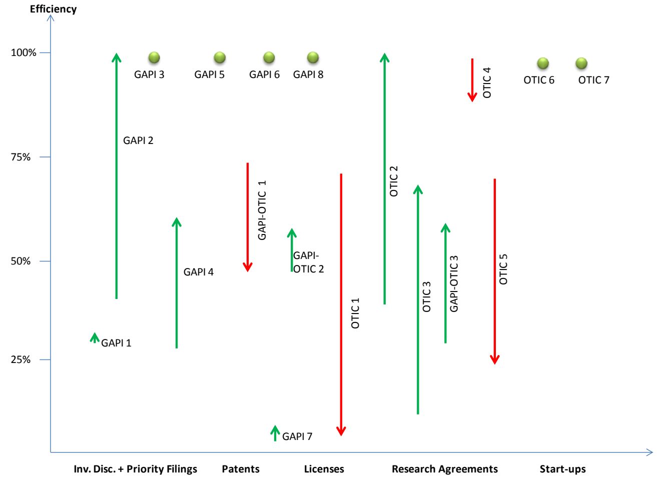
Thus, in our view, the challenge for the Portuguese TTOs is to mimic the improvements occurred in the invention and disclosures (and priority filing) phase in other more downstream, adjacent commercialization stages, most notably addressing new initiatives to reverse the trend that occurs during the creation of start-ups.

4.1.2. Relation between TTO efficiency and some key determinants

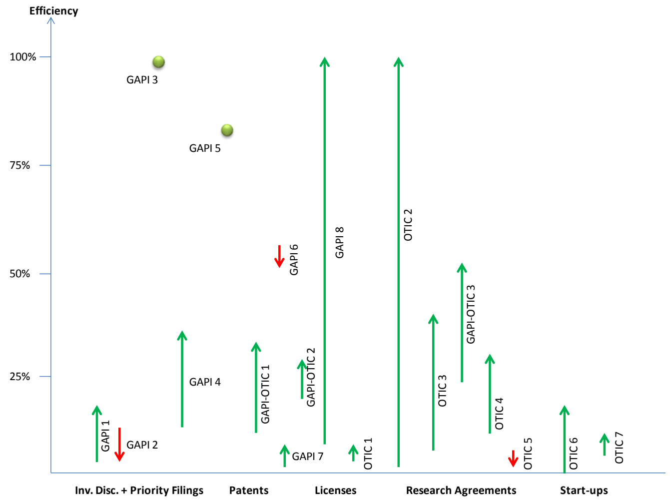
Figure 6 shows the TTOs' relative overall efficiency, in 2011, by group of variables that may potentially be related to TTO efficiency: characteristics of TTOs, Universities and Regions.

Looking first at the characteristics of TTOs – TTO age and TTO size – we conclude that older TTOs tend to be the most efficient (Mean=0.920), although the relationship is not linear. Additionally, on average, smaller TTOs (by number of collaborators in FTE) are the most efficient (Mean=0.915), revealing that the smaller the size of the TTO, the more efficient.

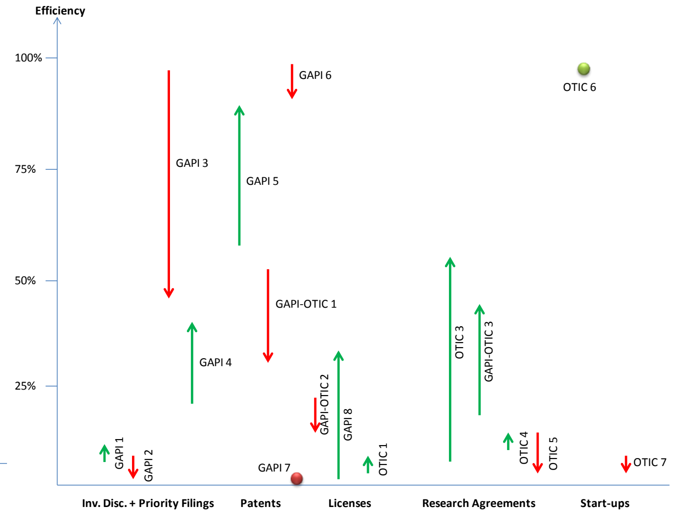
Analyzing the characteristics of universities, we can see that TTOs associated to universities with science parks and medical schools are, in general and on average, more efficient. Moreover, TTOs associated to public universities have lower efficiency values than those associated to private universities (recall, however, that there is only one TTO associated to a private university). In terms of the size of the university, there is a positive linear relationship, meaning that TTOs associated to larger universities are, on average, more efficient. TTOs associated to universities with a lower number of accumulated patents and publications per researcher are less efficient, although in the case of patents, the picture is not so clear cut.



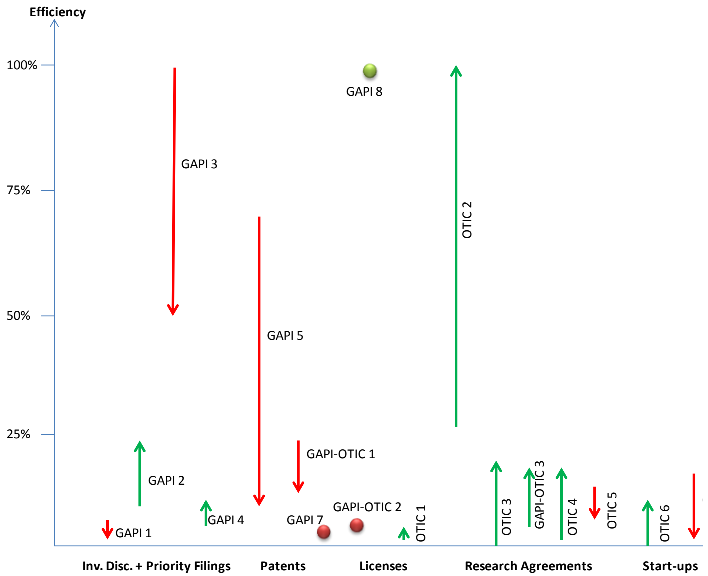
Overall Efficiency



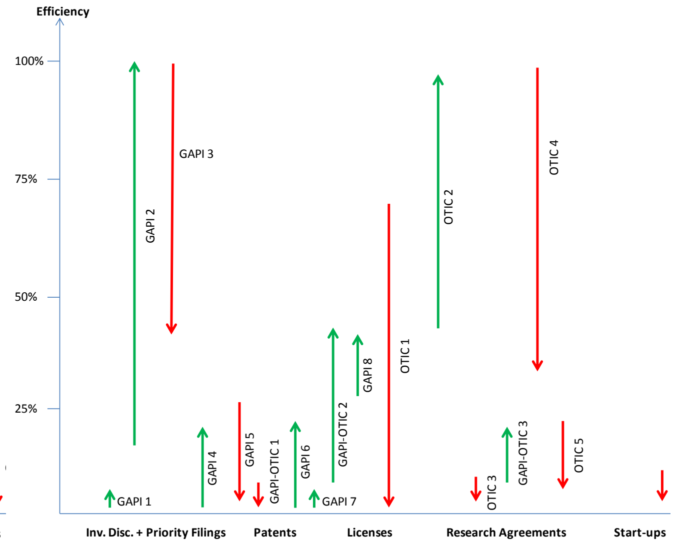
Efficiency in terms of invention disclosures and priority filings



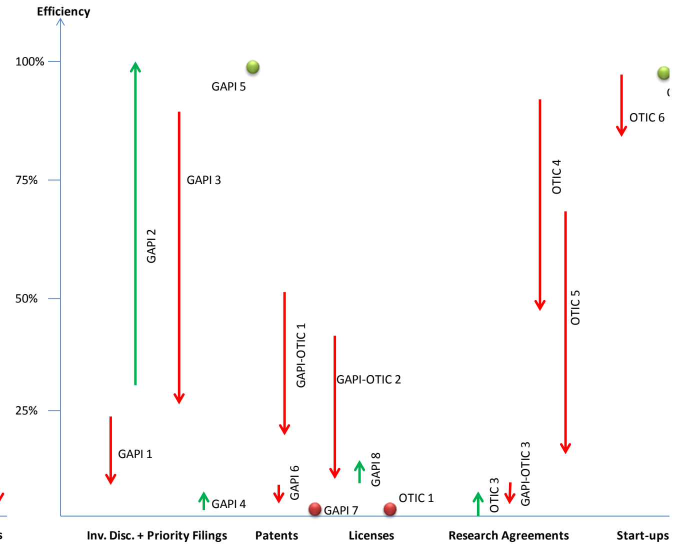
Efficiency in terms of patents granted and active patents



Efficiency in terms of licenses, option agreements, and assignments executed and license income



Efficiency in terms of research agreements



Efficiency in terms of spin-off/start-up companies established

Figure 5: Dynamics (2007-2011) of TTO relative efficiency

Source: Author's computations based on data gathered directly from 18 Portuguese TTOs.

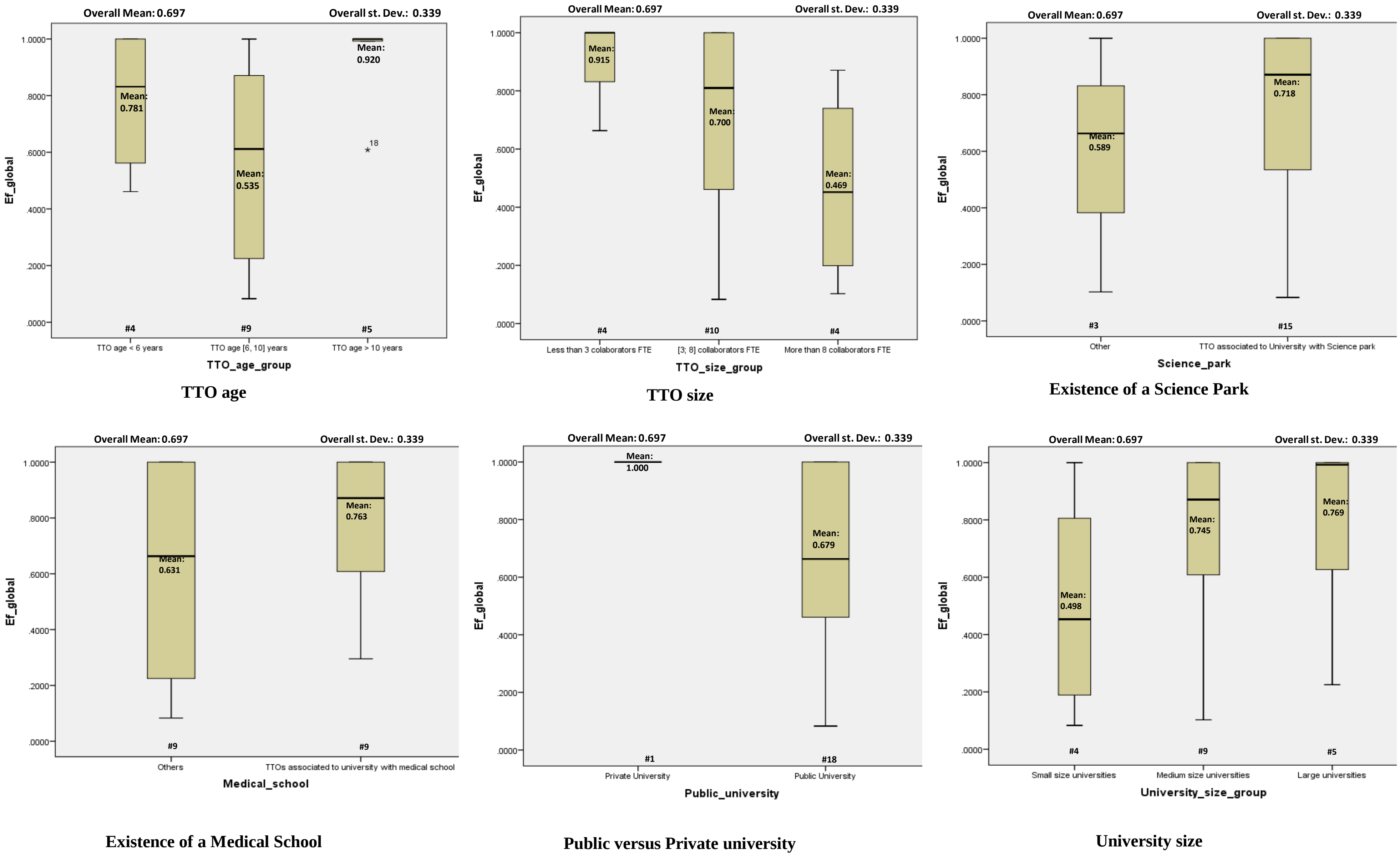
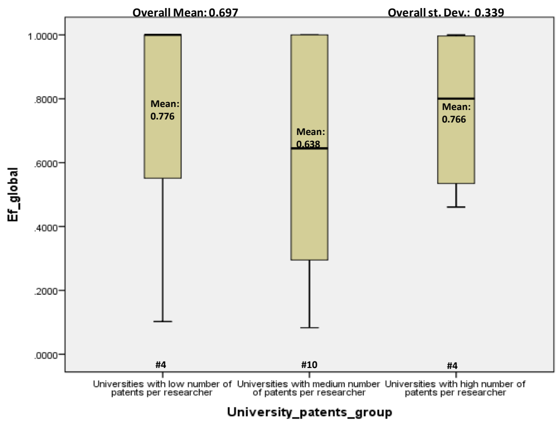
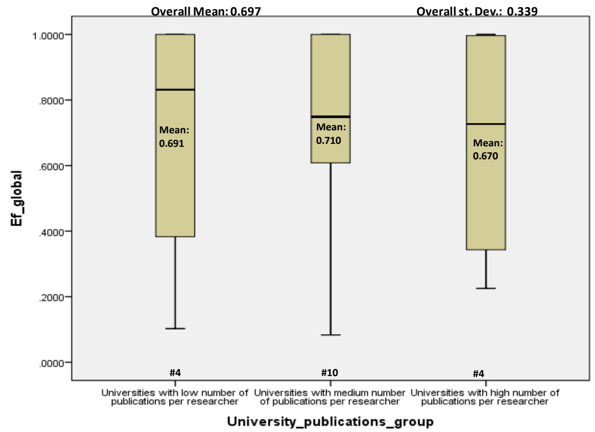


Figure 6: TTO relative overall efficiency (2011) by group of variables concerning the characteristics of TTOs, Universities and Regions

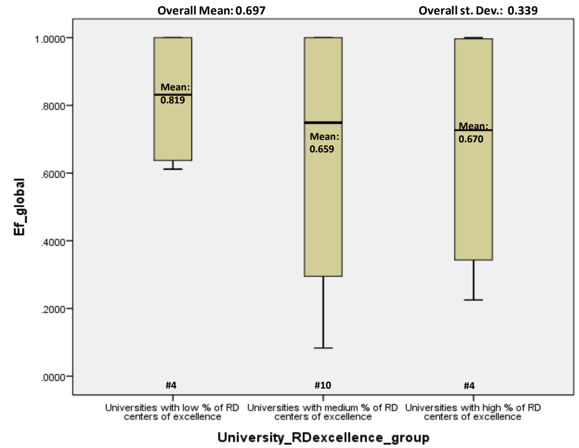
Source: Author's computations based on data gathered directly from 18 Portuguese TTOs.



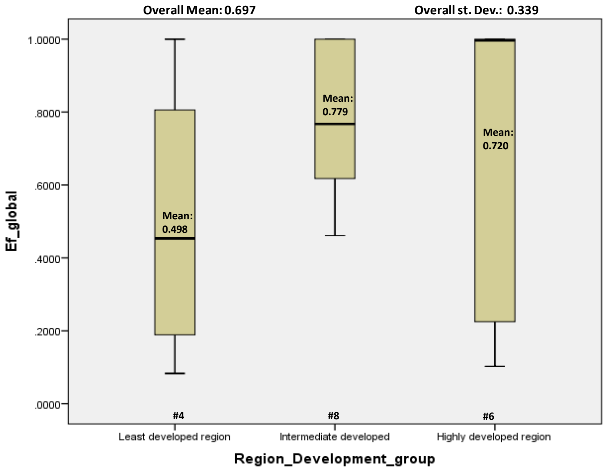
University's patents per researchers



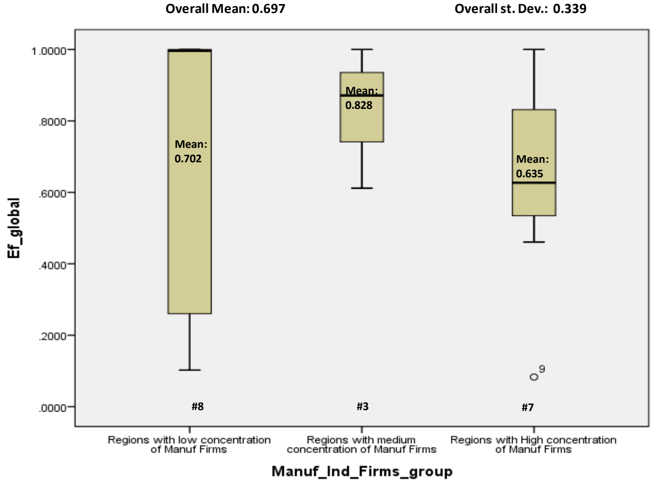
University's publications per researchers



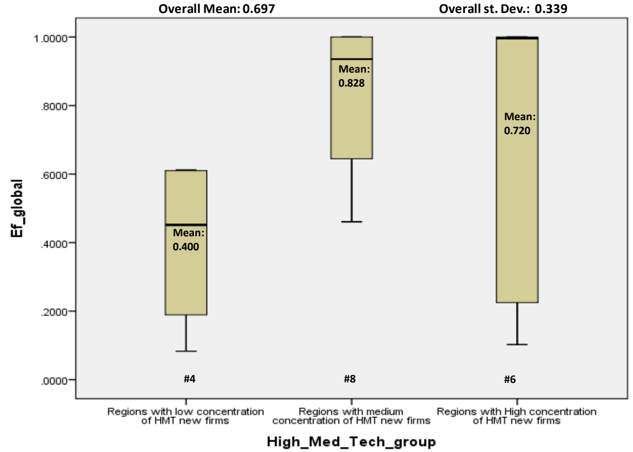
University's share of RD excellence centers



Region's development level



Region's share of manufacturing firms



Region's share of High and Medium Tech new firms

(…) Figure 6: TTO relative overall efficiency (2011) by group of variables concerning the characteristics of TTOs, Universities and Regions

Source: Author's computations based on data gathered directly from 18 Portuguese TTOs.

Additionally, the TTOs associated to universities with a lower proportion of R&D centers classified as excellent are also less efficient.

Finally, analyzing the region's characteristics where TTOs are located, we find a positive linear relation between TTO efficiency and the region's level of development and share of new high-and medium-tech (HMT) firms. Thus, on average, and in an exploratory manner, we could say that TTOs located in highly developed regions and regions with a high concentration of new HMT firms are more efficient. On the other hand, TTOs located in regions with high concentration of manufacturing firms are less efficient.

4.2. Determinants of TTO efficiency: a panel data estimation

The last phase of the research intends to answer this dissertation's main research question: *Do the characteristics of universities impact on the efficiency of the associated TTOs?.*

To this end, we estimate a panel, fixed effect model, which includes (cf. Table 2) all the variables, besides university characteristics, that the literature identified as potential determinants of TTO efficiency (cf. Chapter 2). The estimated models have, in general, good quality of fitness, presenting adjusted R^2 between 41% and 84% (in the case of Model 2, addressing the determinants of TTO efficiency regarding patents granted and active patents, 84.1% of the variance in the efficiency is explained by the model).[5]

Regarding the overall efficiency in the technology transfer process (Model 6), we conclude that university characteristics emerge as crucial factors in the technology transfer process and have a decisive influence on the efficiency of Portuguese TTOs. Specifically, TTOs associated to universities with a large number of accumulated patents have, on average, admitting that all the remaining variables are constant, a positive impact on TTO efficiency. This result is consistent with the literature (Thursby and Kemp, 2002; Di Gregorio and Shane, 2003). The involvement of universities in this field depends on the commercial orientation of university research, and the number of accumulated patents may be a reflection of this orientation (Colombo *et al.*, 2010). Greater commercial orientation facilitates the incorporation of the knowledge produced by universities in industry. The tendency of a university to conduct commercially-

[5] Software: R i386 – version 3.0.1

oriented research increases the chances of discovering technologies and producing knowledge that have commercial value (Di Gregorio and Shane, 2003). Interestingly, a university’s number of scientific publications impacts negatively on TTO efficiency. This result, jointly considered with the previous one on patents, might indicate that in the Portuguese case there is a tradeoff between time and resources allocated to ‘pure basic science’, as translated in scientific publications, and ‘commercially applied science’, as reflected by accumulated patents, with the latter mattering the most to TTO efficiency.

In terms of overall efficiency, it is also possible to conclude that TTOs that are associated to public universities are less efficient than those associated to private universities. Some authors (e.g., Thursby and Kemp, 2002; Siegel *et al*., 2003) argue that public universities/TTOs may be less focused on University-Industry Technology Transfer (UITT) as a source of revenue and may have less flexible UITT policies than private universities, particularly regarding start-up companies and connections with other firms. Our results are in line with this argument, although we have taken into account just one private university.

In the Portuguese case, and contrasting with the general finding that larger universities are associated to more efficient TTOs (O’Shea *et al*., 2005), we find that, on average, all the remaining factors being constant, smaller universities in terms of number of staff dedicated to teaching and research are associated to more efficient TTOs. The question here might be that in the Portuguese case larger universities are not necessarily those that have a higher proportion of staff dedicated to commercially applied research.

In terms of the TTOs’ overall efficiency, regional-related factors failed to emerge as significant determinants, whereas the characteristics of TTOs, namely age and size, seem to matter for TTO efficiency. Indeed, older TTOs tend to be more efficient and larger TTOs tend to be less efficient. Thus, the age/experience of TTOs has relevance on the efficiency of these units, as TTOs with more experience in formal management of technology transfer are better prepared for this process, due to possible “learning by doing” effects, which may consequently facilitate the transfer process and allows for more professionalized TTO staff members (Siegel *et al*., 2003; Conti and Gaulé, 2009; Curi *et al*., 2012). On the other hand, and contrasting with some studies (e.g., Caldera and Debande, 2010; Curi *et al*., 2012), smaller TTOs are, on average, more efficient. This result is, nevertheless, in line with Thursby and Kemp (2002) who suggest that in larger TTOs, the staff may not be sufficiently specialized in the areas where they have specific expertise.

Regarding now the estimation results of the determinants of TTO efficiency by each phase of the technology transfer process (Models 1-5), and starting by analyzing the estimates concerning university characteristics, we can conclude that the presence of a science park and similar infrastructures exerts a positive influence on the efficiency of TTOs in the phase of patents and licenses (Models 2 and 3). The science parks and related infrastructures, by facilitating the interaction between universities and regional industry, tend to have a positive effect on TTO efficiency. This type of infrastructure has been traditionally linked to economic growth and creation of new companies (Castells and Hall, 1994; Phan *et al.*, 2005), but in our case, although the sign of the estimate is positive, it failed to emerge as significant in the case of efficiency regarding the outcome 'start-ups' (Model 5).

We also conclude that universities with medical school are associated with higher TTO efficiency levels in what concerns invention disclosures and priority filings and (granted and active) patents. Our results are consistent with the literature, namely the study by Thursby and Thursby (2002), who also found a positive relation with invention disclosures and patent applications. Such results are in line with Pressman *et al.*'s (1995) justification that "60% of university licensing inventions result from biomedical inventions", and therefore universities with medical schools are more able to achieve good results, by having more efficient TTOs at the earlier stages of the technology transfer process.

University size has a positive influence on TTO efficiency regarding invention disclosures and priority filings (Model 1) and start-up/spin-off companies (Model 5), but a significant negative impact on the TTOs' efficiency related to research agreements (Model 4). The size of the university, in general a proxy for the number of staff dedicated to research, can determine the amount of knowledge that industry may have access to (O'Shea *et al.*, 2005; Colombo *et al.*, 2010). Thus, larger universities can produce more research and potentially more inventions and ideas to be disclosed and more resources are available to new business opportunities, thus contributing to the better performances of the TTOs in terms of invention disclosures and priority filings, as well as new start-ups. This, however, does not necessarily mean alignment of the new knowledge produced and resources available with the existing companies, which might mean that large universities with more resources do not necessarily have more efficient TTOs in what concerns research agreements with (in general) existing companies.

As for the overall TTO efficiency, a university's pool of commercialized knowledge (proxied by the number of accumulated patents) has a significant and positive impact on TTO efficiency in terms of invention disclosures, priority filings, patents granted and active patents. Our data seems therefore to confirm that greater commercial orientation by universities facilitates the incorporation of the knowledge they produce into industry (Di Gregorio and Shane, 2003; Colombo *et al.*, 2010; Cartaxo and Godinho, 2012), especially in the first stages of the technology transfer process. These results are also consistent with the conclusions of Thusrby and Kemp (2002).

In terms of basic scientific knowledge (proxied by the number of publications indexed in ISI), the regression results indicate that TTOs associated to universities with a high number of indexed journal articles tend to be, on average, more efficient than their counterparts in the technology transfer phases of invention disclosures, priority filings (Model 1) and spin-off/start-up companies (Model 5). However, the opposite relation was found regarding the licenses and research agreements phases. The knowledge that is created by the university is essential in the technology transfer process and scientific publications often include novelties that can be exploited by industry (Curi *et al.*, 2012). Those novelties are normally used in the upstream stages of the TT process but also in the creation of start-ups, since they have information that can be useful to business. This therefore justifies the first results. The negative results might derive, as mentioned earlier, from the fact that novel knowledge generated in universities may not be aligned with the industrial basis of the region/country and therefore with the existing firms' needs, which explains the negative impact on the efficiency of TTOs regarding the establishment of research agreements with such firms and the selling of patents through licensing to business entities. The proportion of R&D units classified officially as excellent emerges, when significant, negatively associated to the efficiency of TTOs. Given that FCT classifies R&D centers as excellent based more on their 'research' (scientific publications) than on their 'development' activities, this result is not surprising, which reflect a more scientifically-led orientation of universities against a commercialized orientation.

Regarding the characteristics of TTOs, the results reveal that age/experience appears to have a positive effect on TTO efficiency in the case of research agreements (Model 4).

Powers and McDougall (2005: 299) point out that the learning curve of the TTO's human resources is steep, and stress that "technology transfer literature suggests that institutions with older offices often outperform those with newer offices, perhaps due to the longer time period needed to develop the resource of specific skill sets useful to facilitating technology transfer". Thus, TTOs with more experience in the formal management of technology transfer are better prepared at this stage of the process (Siegel *et al*., 2003; Conti and Gaulé, 2009; Caldera and Debande, 2010). However, we found a negative effect in the efficiency of TTOs regarding the start-ups (Model 5), as younger Portuguese TTOs tend to devote relatively more attention to this downstream phase of the technology process and are co-assisted by other science and technology infrastructures such as science parks and incubators. Caldera and Debande (2010) reached similar results regarding this phase.

Similarly to the TTOs' overall efficiency, TTO size has a negative impact on the efficiency concerning licenses (Model 3), which may again reflect that larger Portuguese TTOs do not possess the appropriate specialized staff in this stage of the technology transfer.

Finally, in what respects regional variables, we found that despite not emerging as significant for the TTOs' overall efficiency (Model 6), they are quite critical both for the very upstream (invention disclosure and priority filings) and downstream (start-ups) phases. On average, and all other factors remaining constant, we realize that TTOs located in highly developed regions with a dense industrial basis, both in terms of manufacturing industry and new high- and medium-tech firms tend to be significantly more efficient in terms of invention disclosure and priority filings and start-ups.

Table 2: Panel data estimations of the determinants of TTOs efficiency (dependent variable: efficiency (in ln), 2007-2011)

	Hypothesis		**Model 1** (invention disclosure + priority filings)	**Model 2** (patents granted + active patents)	**Model 3** (licenses)	**Model 4** (research agreements)	**Model 5** (start-ups)	**Model 6 (Global)**
TTOs characteristics	H 1: Older TTOs tend to be more efficient.	TTO Age	0.022 (0.145)	-0.013 (0.259)	-0.009 (0.709)	0.044*** (0.003)	-0.041*** (0.009)	0.028** (0.015)
	H 2: Larger TTOs tend to be more efficient.	TTO Size	-0.019 (0.241)	-0.015 (0.110)	-0.039** (0.018)	-0.011 (0.496)	0.008 (0.569)	-0.029** (0.029)
University characteristics	H 3: The presence of a science park and similar infrastructures exerts a positive influence on TTO's efficiency.	Science Park	0.368 (0.548)	0.464*** (0.005)	0.618** (0.025)	-0.173 (0.491)	0.227 (0.382)	0.288 (0.179)
	H 4: Universities with medical school tend to be associated with high efficiency TTOs.	Medical School	0.478** (0.026)	0.158*** (0.004)	0.194 (0.117)	-0.076 (0.476)	0.105 (0.227)	-0.032 (0.724)
	H 5: TTOs that are associated to public universities are more efficient than those associated to private universities.	Public University	-0.209 (0.410)	-0.123 (0.541)	0.115 (0.754)	0.200 (0.295)	0.024 (0.962)	-0.303* (0.065)
	H 6: TTOs that are associated to larger universities tend to be more efficient.	University Size	0.001* (0.080)	0.000 (0.922)	0.000 (0.383)	-0.001*** (0.000)	0.001** (0.038)	-0.0003** (0.042)
	H 7: A highest number of accumulated patents by a university have a positive impact on TTO's efficiency.	Patents	0.002*** (0.003)	0.004*** (0.000)	-0.001 (0.293)	-0.001* (0.086)	0.000 (0.560)	0.002*** (0.003)
	H 8: The number of scientific publications and R&D excellence centers of a university exerts a positive influence on TTO's efficiency.	Publications	0.546*** (0.008)	-0.067 (0.197)	-0.180* (0.069)	-0.291*** (0.008)	0.156* (0.051)	-0.299*** (0.001)
		R&D Excellence	-0.014** (0.019)	-0.009* (0.087)	0.004 (0.721)	-0.002 (0.617)	-0.023** (0.010)	0.003 (0.397)
Regional context	H 9: Regional economic development exerts a positive influence on TTO's efficiency.	Purchasing Power index	0.235*** (0.001)	0.115 (0.191)	0.176 (0.347)	0.144*** (0.005)	0.187*** (0.002)	0.062 (0.127)
	H 10: Regional industrial basis exerts a positive influence on TTO's efficiency.	Manufacturing industry firms	7.524* (0.080)	0.095 (0.960)	1.699 (0.693)	1.271 (0.522)	6.425** (0.011)	-2.035 (0.235)
		High and medium tech new firms	27.982** (0.037)	15.390* (0.077)	29.081** (0.029)	3.652 (0.821)	24.011* (0.100)	18.707 (0.152)
		N	90	90	90	90	90	90
		Adjusted R2	0.640	0.841	0.516	0.405	0.704	0.539

Legend: ***(**)[*] statistically significant at 1%(5%)[10%]

Note: 90 observations (5 years*18 TTOs)

The literature (Chapple *et al*., 2005; Curi *et al*., 2012) reached similar results, stressing that TTOs located in regions with higher levels of GDP (and R&D) tend to be more efficient in technology transfer as a result of higher regional spillovers in technology transfer. Our results in terms of the influence of manufacturing firms and new high- and medium-technology firms (on invention disclosures, priority filings, patents, licenses and start-ups) reinforce this spillover influence on TTO efficiency. These strong regional effects lead us to suggest that in some regions, due to lower economic activity and industrial density, TTOs will be less efficient in the commercialization of technology.

Conclusions

In this work, we assessed the evolution of the efficiency of Portuguese TTOs in the last ten years, and additionally, evaluated the extent to which the characteristics of universities impact on the efficiency of the associated TTOs.

In the efficiency analysis we found that the TTOs improved efficiency especially in the most upstream stages of the technology transfer process – invention disclosures and priority filings. In contrast, in the most downstream stages – spin-off/start-up companies established – the trend reversed: nine TTOs lost efficiency and just four improved their performance. Although efficiency improvement in the upstream stage of the technology transfer process is encouraging, given the efforts by both public authorities and universities put into TTO staff training in invention disclosures and IPR awareness, the drop in efficiency in stages close to the effective commercialization of technology is cause for concern and calls for renewed efforts in this regard.

The estimation results on the determinants of TTO efficiency show that university characteristics are a crucial factor for the technology transfer process and have a decisive influence on the efficiency of Portuguese TTOs. However, the tendency of this influence varies depending on the stage of the process. This analysis highlights the greater importance of university characteristics in the upstream phase of the technology transfer process - TTOs associated to universities with a large number of accumulated patents and publications have, on average, a positive influence on TTO efficiency in terms of invention disclosures and priority filings. To stimulate this trend, local and national authorities should maintain the quality of the research that is conducted in Portuguese universities and possibly define new objectives for lecturers/researchers in terms of number of publications.

Regional variables (manufacturing firms, new high- and medium-tech firms, and purchasing power index) have a significant impact on both the very upstream (invention disclosure and priority filings) and downstream (start-ups) phases, clearly revealing that there is a strong regional spillover influence on TTO efficiency. Consequently, the government could organize TTOs on a regional basis to offer additional assistance to both universities and firms. The potential advantage of using regional TTOs is that they may facilitate the emergence of specialist teams for different industry sectors and may also enable the development of a critical mass of expertise and experience (Chapple *et al.*, 2005).

The efficiency of Portuguese TTOs is very low in terms of 'licenses' and 'research agreements'. This is likely to be explained, at least in part, by a lack of alignment between the local industrial basis and the knowledge produced by universities. Thus, U-I linkages should be promoted, namely through a greater integration of university PhDs in firms, having TTOs act as intermediaries and, at the same time, allowing TTO staff to have on-site training in companies. The science parks that are near the universities are an important part of this process, as they have a greater proximity to companies, but if they are to operate as an efficiency booster, they should be integrated with TTOs in a common value chain. Universities and technology transfer offices should therefore synchronize the depth of their organizational support to obtain the most of their local industrial basis (Wright *et al.*, 2012).

To sum up, the main challenge for Portuguese TTOs is to improve efficiency in downstream stages, particularly in the creation of start-ups, and continue to feed the entire process upstream. In recent years, UTEN has contributed through the provision of training/internships and workshops for TTO efficiency in the upstream stages of the technology transfer process. The next step is to strengthen the existing network by promoting further the interaction between universities and industry so as to increase the flow of real, productive, market value technology transfer deals and venture creation, such that the knowledge generated by Portuguese universities may be put into productive use towards enhancing the competitiveness of the Portuguese economy. Following the important work developed so far by UTEN, summarized in its Progress Report 2007-2012 (UTEN, 2012), Portuguese authorities should put policy measures in place aimed at stimulating a culture of cooperation between universities and industry, which will allow high value added research and development performed in Portuguese S&T infrastructures to be transformed into competitive, marketable products and services for the international markets in the near future.

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Appendix

Table A1: Determinants of TTO's efficiency. Literature Review

Hypotheses	Country	Study	Number of observations	Methodology	Dummy variable: 1;0	Dependent variable: efficiency	Relation	notes
Presence of a Medical School	USA	Thursby and Thursby, 2002	65	TFP (Total Factor Productivity) - based on DEA	1	Invention Disclosures	(+)	
						Patent Aplications	(+)	
						Licenses Executed	(-)	
		Thursby and Kemp, 2002	112	DEA	1	DEA_number of licenses executed	(-)*	* Weak evidence - statistical significance threshold of 5%. The authors concluded that this determinant is insignificant.
						DEA_the amount of industry sponsored research		
						DEA_the number of new patent applications		
						DEA_the number of invention disclosures		
						DEA_the amount of royalties received		
		Siegel et al., 2003	55	SFE	1	SFE_average annual number of licensing agreements	(-)	Weak evidence
						SFE_average annual licensing revenue	(+)	
		Anderson et al., 2007	54	DEA	1	DEA_ licensing income	(-)*	* Weak evidence - statistical significance threshold of 5%. The authors concluded that this determinant is insignificant.
						DEA_licenses and options executed		
						DEA_startup companies		
						DEA_US patents field		
						DEA_US patents issued		

(...)

Hypotheses	Country	Study	Number of observations	Methodology	Dummy variable: 1;0	Dependent variable: efficiency	Relation	notes
	UK	Chapple et al., 2005	50	DEA ; SFE	1	DEA_number of licenses	(...)	
						DEA_licensing income	(- -)	
						SFE_number of licenses	(...)	
						SFE_licensing income	(- -)	
	Spain	Caldera and Debande, 2010	52	Simple linear regression	1	R&D income	(+)	
						Number R&D contracts	(+ + +)	
						licensing income	(-)	
						number of licenses	(…)	Weak evidence
						number of spin-offs	(...)	
	France	Curi et al., 2012	51	DEA (two-stage semi-parametric bootstrap-based)	1	DEA_number of patent applications	(- -)	(Second-stage regression results)
						DEA_number of patents with submitted extensions	(- -)	
						DEA_number of extensions required	(- -)	
						DEA_number of software applications	(- -)	
	USA and UK	Siegel et al., 2008	120	multiple-output distance function from a parametric approach	1	number of licenses	(+)	
						licensing income	(+)	
						number of universitiy startups generated	(+)	

(…)

Hypotheses	Country	Study	Number of observations	Methodology		Dummy variable: 1;0	Dependent variable: efficiency	Relation notes
TTO age	USA	Thursby and Thursby, 2002	65	TFP (Total Factor Productivity) - based on DEA	0	Invention Disclosures	0	
						Patent Aplications		
						Liceses Executed		
		Thursby and Kemp, 2002	112	DEA	0	DEA_number of licenses executed	0	0 = not studied
						DEA_the amount of industry sponsored research		
						DEA_the number of new patent applications		
						DEA_the number of invention disclosures		
						DEA_the amount of royalties received		
		Siegel et al., 2003	55	SFE	1	SFE_average annual number of licensing agreements	(+)	weak evidence
						SFE_average annual licensing revenue	(+ +)	5% significance
		Anderson et al., 2007	54	DEA	0	DEA_ licensing income	0	
						DEA_licenses and options executed		
						DEA_startup companies		
						DEA_US patents field		
						DEA_US patents issued		
	UK	Chapple et al., 2005	50	DEA ; SFE	1	DEA_number of licenses	(-)	Older TTO's are less efficient - strong evidence
						DEA_licensing income	(...)	

(...)

Hypotheses	Country	Study	Number of observations	Methodology	Dummy variable: 1;0	Dependent variable: efficiency	Relation	notes
						SFE_number of licenses	(-)	
						SFE_licensing income	(...)	
	Spain	Caldera and Debande, 2010	52	Simple linear regression	1	R&D income	(+ + +)	
						Number R&D contracts	(+ + +)	
						licensing income	(-)	
						number of licenses	(+)	
						number of spin-offs	(-)	
	France	Curi et al., 2012	51	DEA (two-stage semi-parametric bootstrap-based)	1	DEA_number of patent applications	(+)	(Second-stage regression results)
						DEA_number of patents with submitted extensions	(+)	
						DEA_number of extensions required	(+)	
						DEA_number of software applications	(+)	
	USA and UK	Siegel et al., 2008	120	multiple-output distance function from a parametric approach	1	number of licenses	(…)	
						licensing income	(- -)	
						number of universitiy startups generated	(…)	
TTO ownership (PUB)	USA	Thursby and Thursby, 2002	65	TFP (Total Factor Productivity) - based on DEA	1	Invention Disclosures	(-)	Public Universities
						Patent Aplications	(+)	
						Liceses Executed	(-)	
		Thursby and Kemp, 2002	112	DEA	1	DEA_number of licenses executed	(-)	The probability of efficiency for a private school is more than four times that of a public school, all other factors held constant.
						DEA_the amount of industry sponsored research		

(...)

Hypotheses	Country	Study	Number of observations	Methodology	Dummy variable: 1;0	Dependent variable: efficiency	Relation	notes
						DEA_the number of new patent applications		
						DEA_the number of invention disclosures		
						DEA_the amount of royalties received		
		Siegel et al., 2003	55	SFE	1	SFE_average annual number of licensing agreements	(-)	
						SFE_average annual licensing revenue	(-)	
		Anderson et al., 2007	54	DEA	1	DEA_ licensing income	n.e. (…)	
						DEA_licenses and options executed		
						DEA_startup companies		
						DEA_US patents field		
						DEA_US patents issued		
	UK	Chapple et al., 2005	50	DEA ; SFE	0	DEA_number of licenses	0	
						DEA_licensing income		
						SFE_number of licenses		
						SFE_licensing income		
	Spain	Caldera and Debande, 2010	52	Simple linear regression	1	R&D income	(+ + +)	
						Number R&D contracts	(+ + +)	
						licensing income	(…)	weak evidence
						number of licenses	(- - -)	
						number of spin-offs	(…)	
	France	Curi et al., 2012	51	DEA (two-stage semi-parametric bootstrap-based)	0	DEA_number of patent applications	0	
						DEA_number of patents with submitted extensions		
						DEA_number of extensions required		
						DEA_number of software applications		

(...)

Hypotheses	Country	Study	Number of observations	Methodology	Dummy variable: 1;0	Dependent variable: efficiency	Relation	notes
	USA and UK	Siegel et al., 2008	120	multiple-output distance function from a parametric approach	0	number of licenses	0	
						licensing income		
						number of universitiy startups generated		
TTO size	USA	Thursby and Thursby, 2002	65	TFP (Total Factor Productivity) - based on DEA	0	Invention Disclosures	0	
						Patent Aplications		
						Liceses Executed		
		Thursby and Kemp, 2002	112	DEA	1	DEA_number of licenses executed	(-)	
						DEA_the amount of industry sponsored research		
						DEA_the number of new patent applications		
						DEA_the number of invention disclosures		
						DEA_the amount of royalties received		
		Siegel et al., 2003	55	SFE	0	SFE_average annual number of licensing agreements	0	
						SFE_average annual licensing revenue		
		Anderson et al., 2007	54	DEA	0	DEA_ licensing income	0	
						DEA_licenses and options executed		
						DEA_startup companies		
						DEA_US patents field		
						DEA_US patents issued		
	UK	Chapple et al., 2005	50	DEA ; SFE	0	DEA_number of licenses	0	
						DEA_licensing income		
						SFE_number of licenses		
						SFE_licensing income		

(...)

Hypotheses	Country	Study	Number of observations	Methodology	Dummy variable: 1;0	Dependent variable: efficiency	Relation	notes
	Spain	Caldera and Debande, 2010	52	Simple linear regression	1	R&D income	(+ + +)	
						Number R&D contracts	(+ + +)	
						licensing income	(…)	weak evidence
						number of licenses	(+ +)	
						number of spin-offs	(+)	
	France	Curi et al., 2012	51	DEA (two-stage semi-parametric bootstrap-based)	1	DEA_number of patent applications	(+ + +)	(Second-stage regression results)
						DEA_number of patents with submitted extensions	(+ + +)	
						DEA_number of extensions required	(+ + +)	
						DEA_number of software applications	(+ + +)	
	USA and UK	Siegel et al., 2008	120	multiple-output distance function from a parametric approach	0	number of licenses	0	
						licensing income		
						number of universitiy startups generated		
Regional R&D	USA	Thursby and Thursby, 2002	65	TFP (Total Factor Productivity) - based on DEA	0	Invention Disclosures	0	
						Patent Aplications		
						Licenses Executed		
		Thursby and Kemp, 2002	112	DEA	0	DEA_number of licenses executed	0	
						DEA_the amount of industry sponsored research		
						DEA_the number of new patent applications		
						DEA_the number of invention disclosures		
						DEA_the amount of royalties received		

(...)

Hypotheses	Country	Study	Number of observations	Methodology	Dummy variable: 1;0	Dependent variable: efficiency	Relation	notes
Regional R&D		Siegel et al., 2003	55	SFE	1	SFE_average annual number of licensing agreements	(+ +)	positive relation on "annual industry R&D intesity"
						SFE_average annual licensing revenue		
		Anderson et al., 2007	54	DEA	0	DEA_ licensing income	0	
						DEA_licenses and options executed		
						DEA_startup companies		
						DEA_US patents field		
						DEA_US patents issued		
	UK	Chapple et al., 2005	50	DEA ; SFE	1	DEA_number of licenses	(+ + +)	Universities located in regions with higher levels of R&D and GDP are more efficient in TT
						DEA_licensing income	(-)	weak evidence
						SFE_number of licenses	(+ + +)	
						SFE_licensing income	(-)	weak evidence
	Spain	Caldera and Debande, 2010	52	Simple linear regression	0	R&D income	0	
						Number R&D contracts		
						licensing income		
						number of licenses		
						number of spin-offs		
	France	Curi et al., 2012	51	DEA (two-stage semi-parametric bootstrap-based)	1	DEA_number of patent applications	(+ +)	(Second-stage regression results)
						DEA_number of patents with submitted extensions	(+ +)	
						DEA_number of extensions required	(+ +)	
						DEA_number of software applications	(+ +)	
	USA/UK	Siegel et al., 2008	120	multiple-output distance function from a parametric approach	1	number of licenses	(+ +)	
						licensing income	(…)	
						number of universitiy startups generated	(…)	

(...)

Hypotheses	Country	Study	Number of observations	Methodology	Dummy variable: 1;0	Dependent variable: efficiency	Relation	notes
Presence of a Science Park	USA	Thursby and Thursby, 2002	65	TFP (Total Factor Productivity) - based on DEA	0	Invention Disclosures	0	
						Patent Aplications		
						Liceses Executed		
		Thursby and Kemp, 2002	112	DEA	0	DEA_number of licenses executed	0	
						DEA_the amount of industry sponsored research		
						DEA_the number of new patent applications		
						DEA_the number of invention disclosures		
						DEA_the amount of royalties received		
		Siegel et al., 2003	55	SFE	0	SFE_average annual no. of licensing agreements	0	
						SFE_average annual licensing revenue		
		Anderson et al., 2007	54	DEA	0	DEA_ licensing income	0	
						DEA_licenses and options executed		
						DEA_startup companies		
						DEA_US patents field		
						DEA_US patents issued		
	UK	Chapple et al., 2005	50	DEA ; SFE	0	DEA_number of licenses	0	
						DEA_licensing income		
						SFE_number of licenses		
						SFE_licensing income		
	Spain	Caldera and Debande, 2010	52	Simple linear regression	1	R&D income	(…)	
						Number R&D contracts	(+ + +)	
						licensing income	(…)	
						number of licenses	(…)	
						number of spin-offs	(…)	
	France	Curi et al., 2012	51	DEA (two-stage semi-parametric bootstrap-based)	0	DEA_number of patent applications	0	(Second-stage regression results)
						DEA_number of patents with submitted extensions		
						DEA_number of extensions required		
						DEA_number of software applications		
	USA and UK	Siegel et al., 2008	120	multiple-output distance function from a parametric approach	1	number of licenses	(…)	
						licensing income	(…)	
						number of university startups generated	(…)	